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(54) APPARATUS AND METHODS FOR WIRELESS COMMUNICATION IN POWER-RESTRICTED FREQUENCY BANDS

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H04B 7/06	(2006.01)
H04B 7/08	(2006.01)

(52) **U.S. Cl.**

CPC ***H04B 7/0602*** (2013.01); ***H04B 7/0811*** (2013.01); ***H04B 7/0814*** (2013.01)

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CPC H04B 7/0691; H04B 7/0619; H04L 25/0204; H04L 25/0226; H04L 27/2647

USPC 375/260, 267, 219; 370/477; 455/133–135, 67.13, 67.14, 101, 513

See application file for complete search history.

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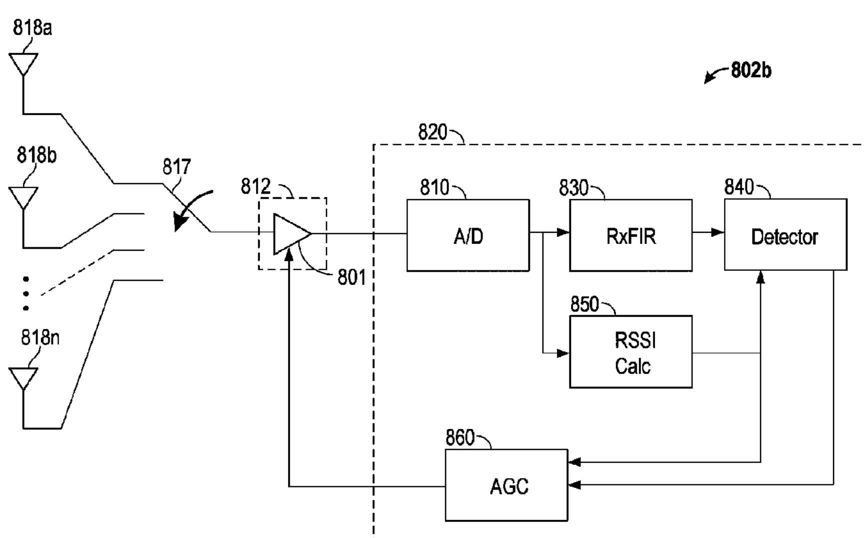
(57) **ABSTRACT**

Apparatuses, methods, and devices for wireless communication. One aspect of the subject matter described in the disclosure provides a method of selecting one of a plurality of antennas. The method includes receiving, at a first antenna, a first training field of a training frame. The method further includes receiving, at a second antenna, a second training field of the training frame. The method further includes selecting one of the first and second antennas based on at least one training field.

33 Claims, 11 Drawing Sheets



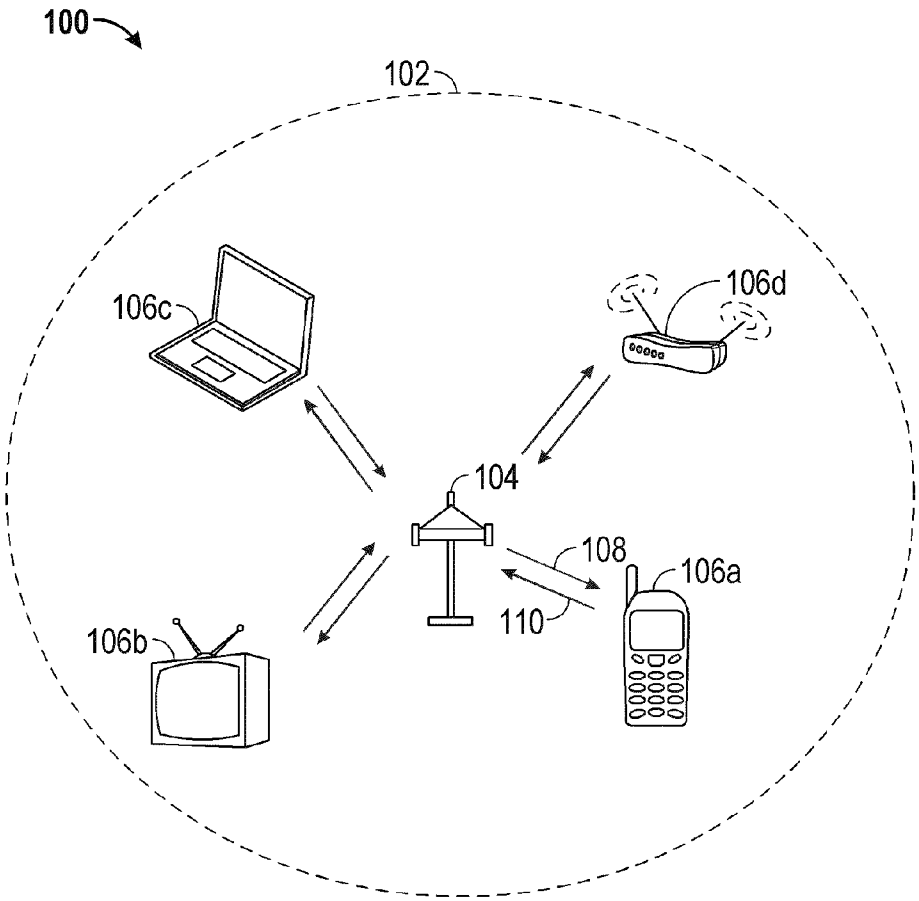


FIG. 1

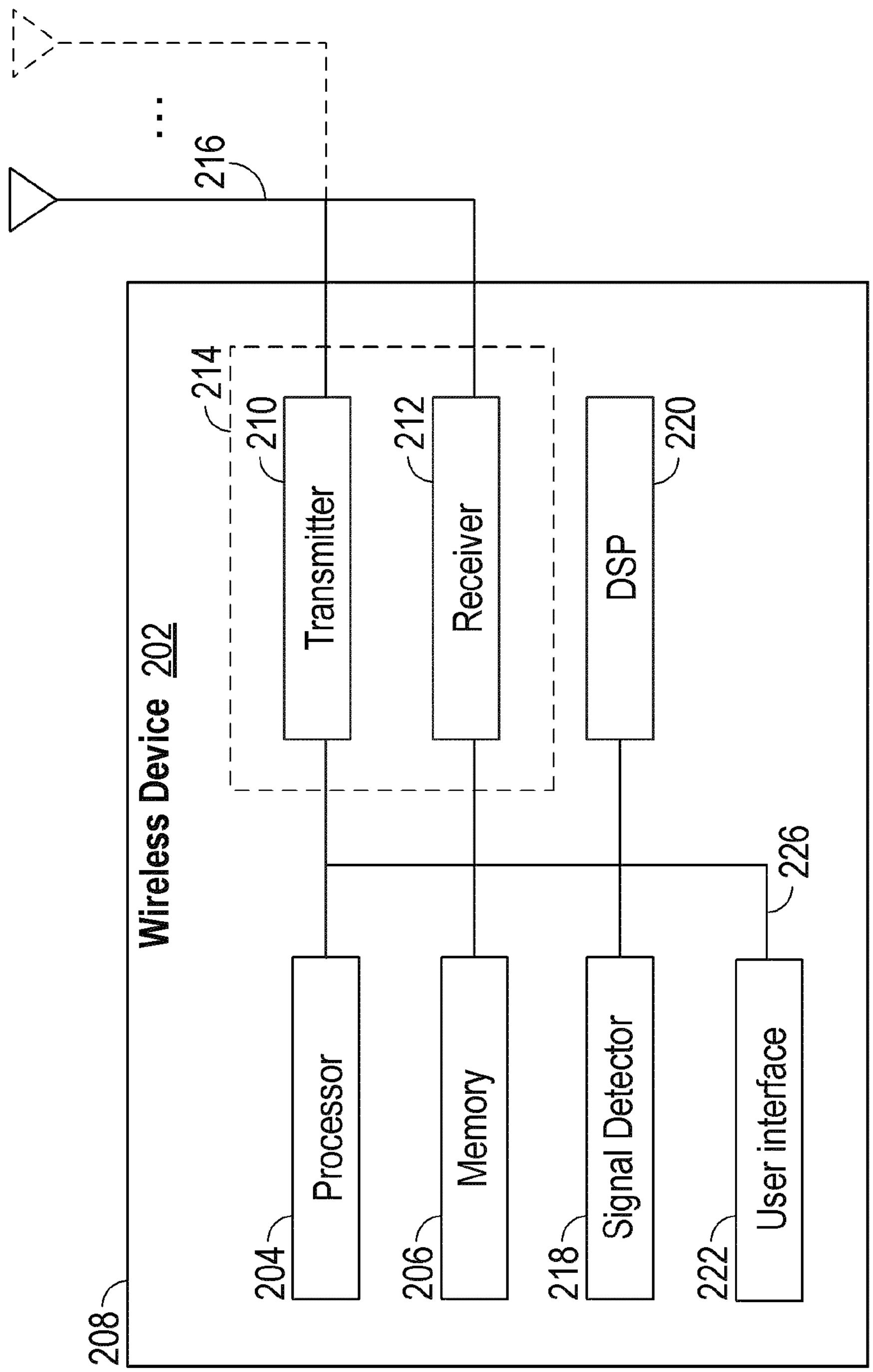

Wireless Device 202
208
216
214
Transmitter
210
Receiver
212
DSP
220
226
Processor
204
Memory
206
Signal Detector
218
User interface
222

FIG. 2

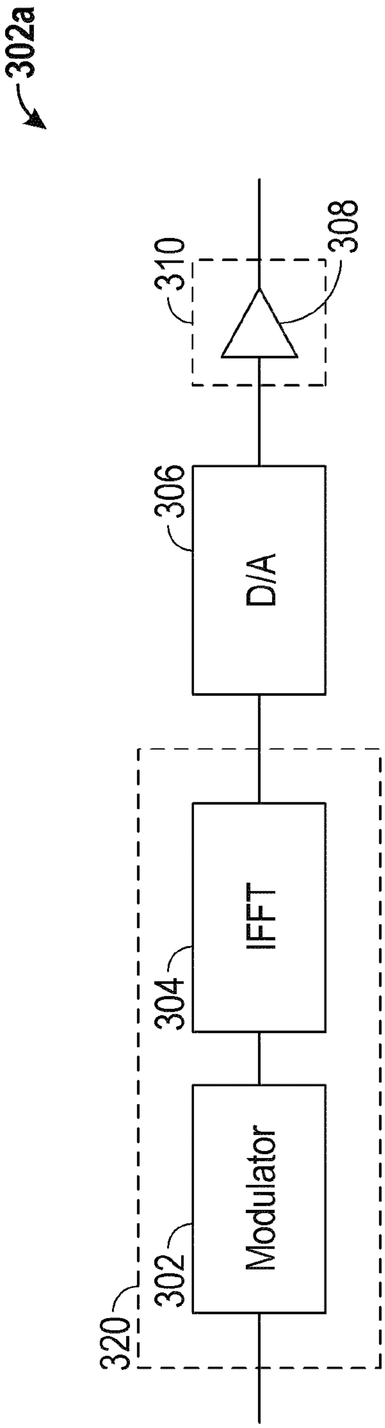

302a
Modulator
IFFT
D/A
302
304
306
308
310
320

FIG. 3

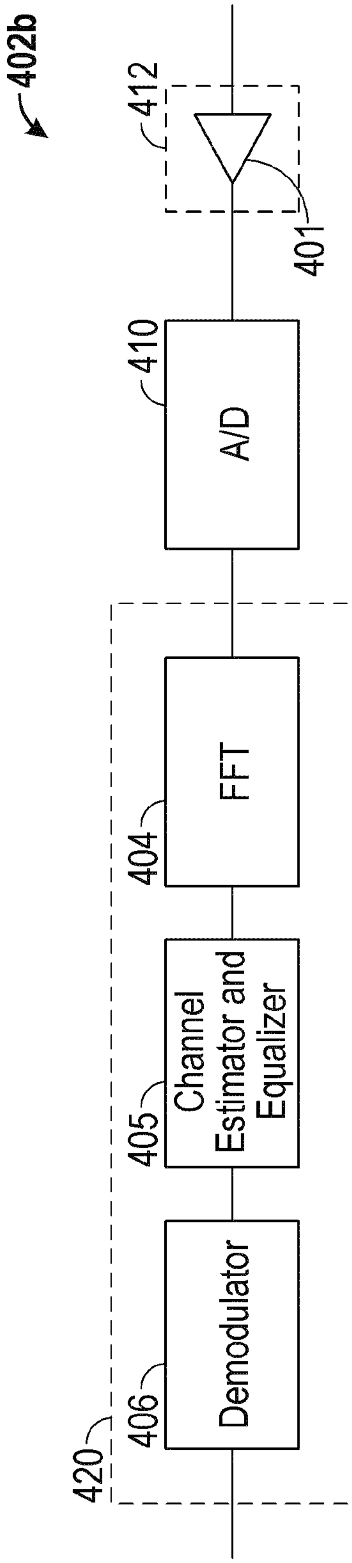
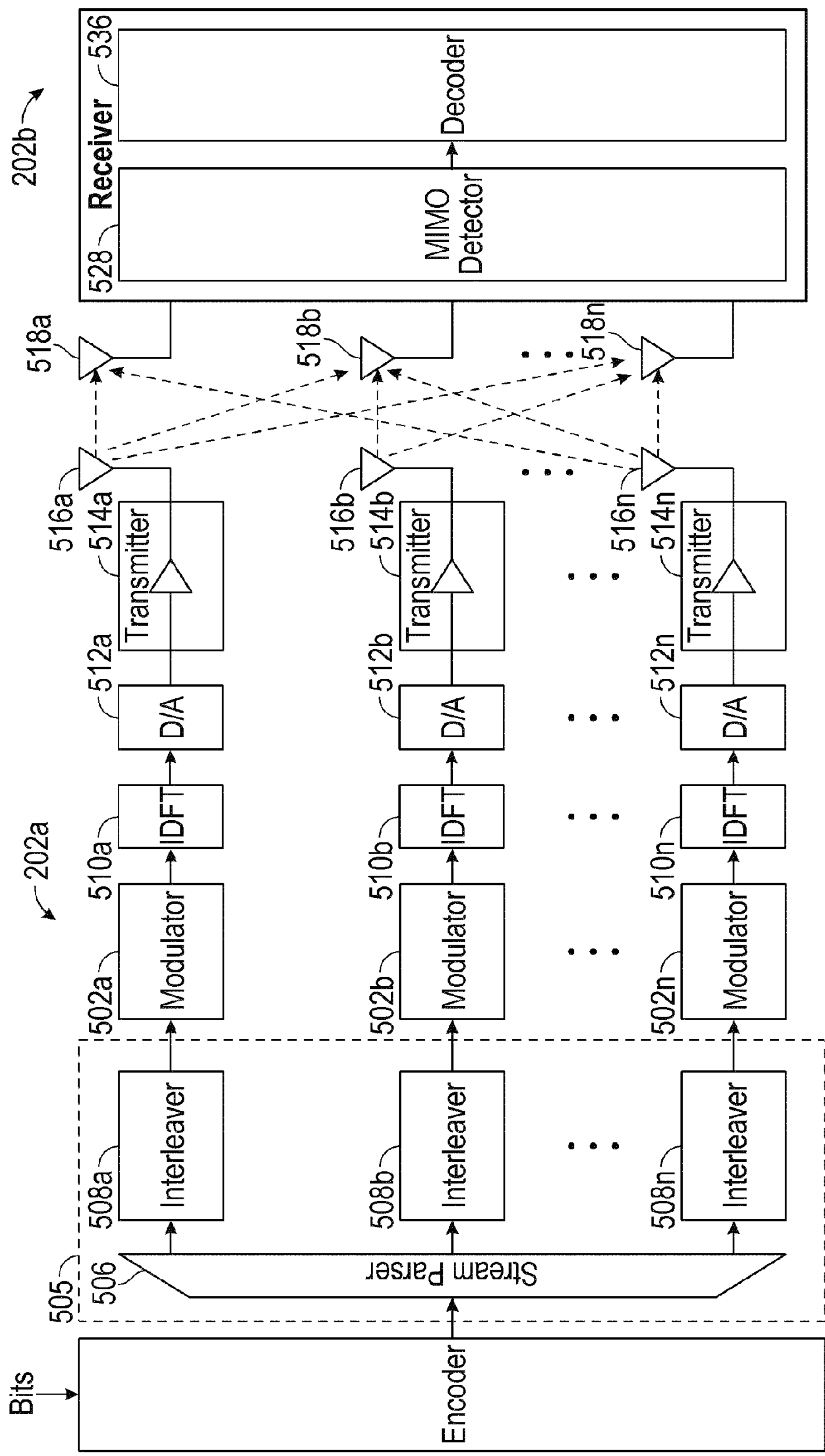

402b
Demodulator
Channel Estimator and Equalizer
FFT
A/D
401
404
405
406
410
412
420

FIG. 4



Bits
Encoder
504
505
506
Stream Parser
508a
508b
508n
Interleaver
502a
502b
502n
Modulator
510a
510b
510n
IDFT
512a
512b
512n
D/A
514a
514b
514n
Transmitter
516a
516b
516n
518a
518b
518n
202a
202b
Receiver
528
MIMO Detector
536
Decoder

FIG. 5

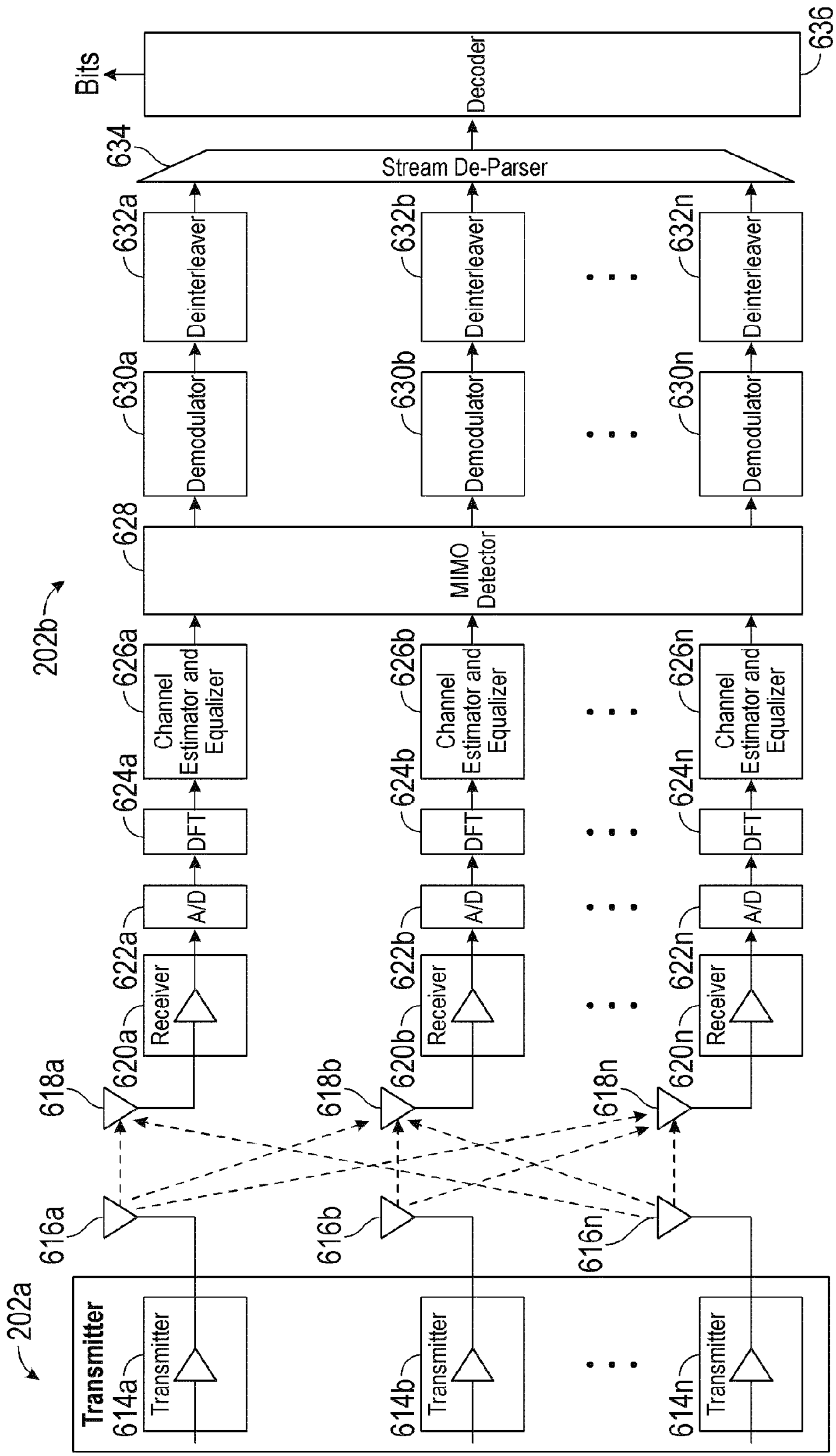

Bits
Decoder
636
634
Stream De-Parser
632a
Deinterleaver
632b
Deinterleaver
632n
Deinterleaver
630a
Demodulator
630b
Demodulator
630n
Demodulator
628
MIMO Detector
202b
626a
Channel Estimator and Equalizer
626b
Channel Estimator and Equalizer
626n
Channel Estimator and Equalizer
624a
DFT
624b
DFT
624n
DFT
A/D
A/D
A/D
622a
Receiver
622b
Receiver
622n
Receiver
620a
620b
620n
618a
618b
618n
616a
616b
616n
202a
Transmitter
614a
Transmitter
614b
Transmitter
614n
Transmitter

FIG. 6

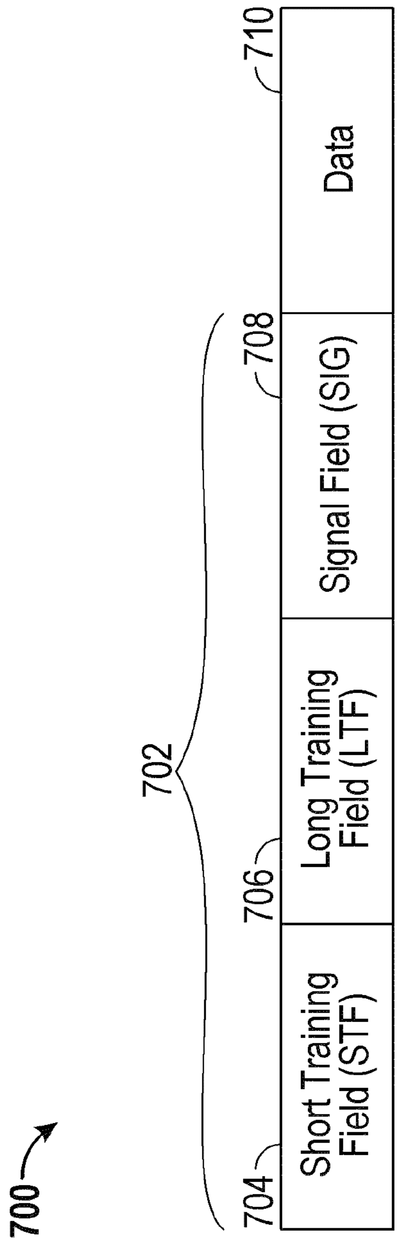

700
702
704
Short Training Field (STF)
706
Long Training Field (LTF)
708
Signal Field (SIG)
710
Data

FIG. 7

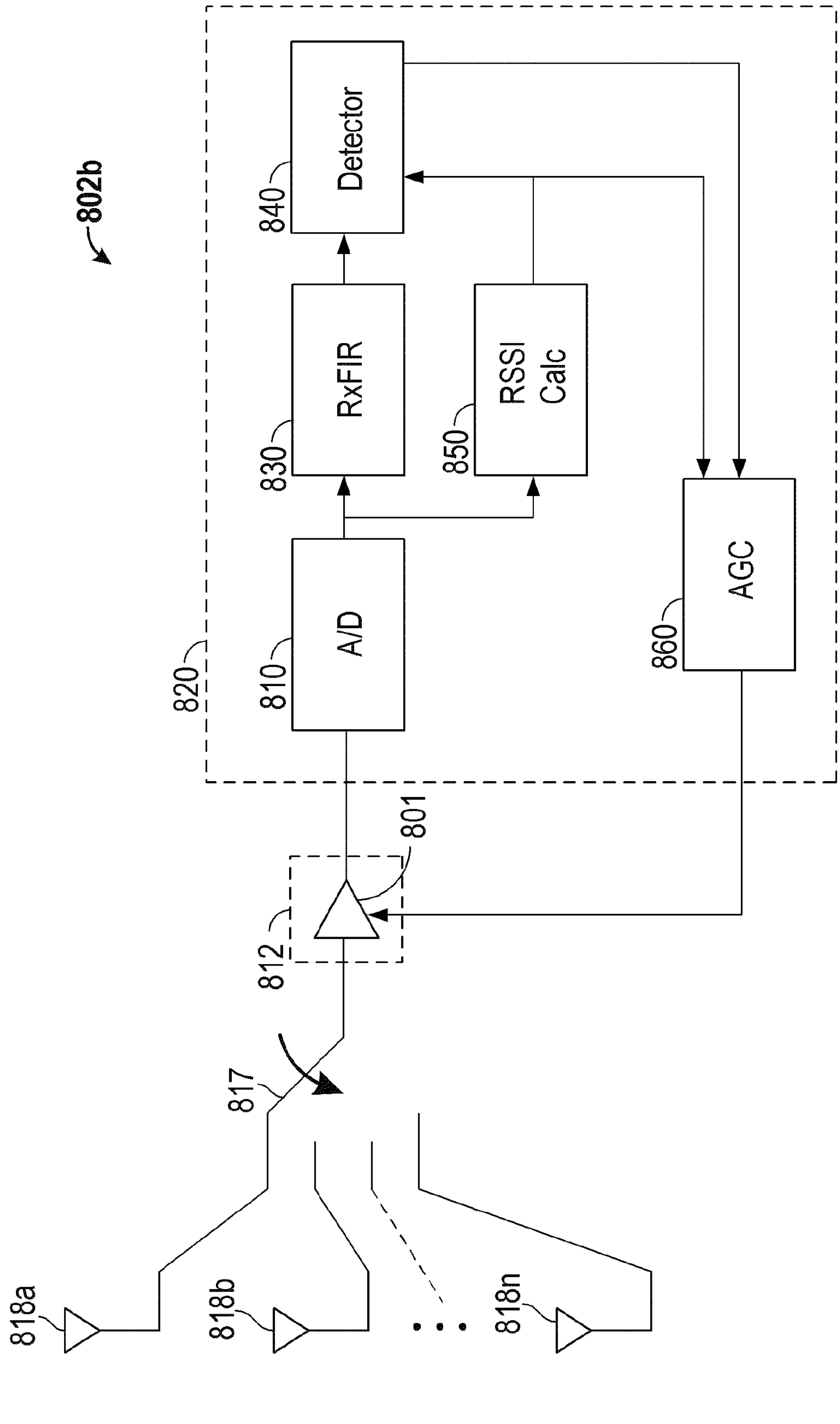

802b
820
810
A/D
830
RxFIR
840
Detector
850
RSSI
Calc
860
AGC
801
812
817
818a
818b
818n

FIG. 8

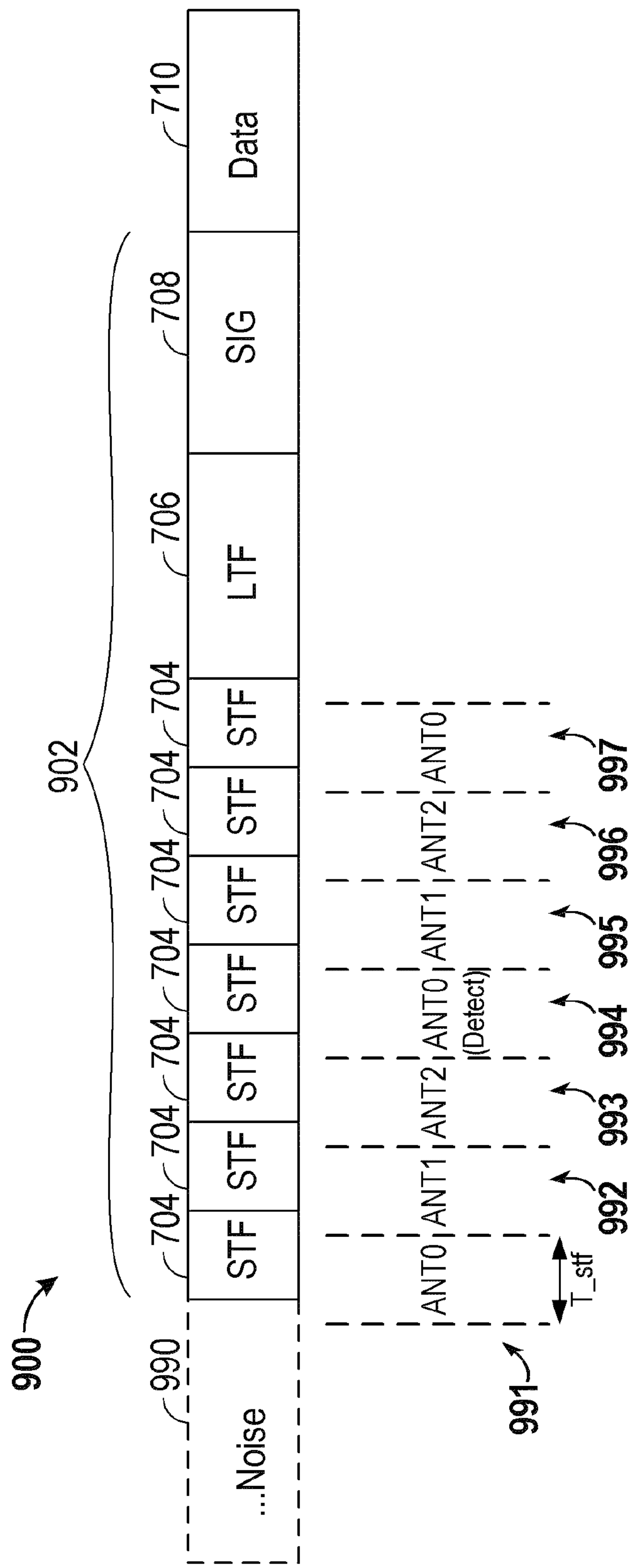

900
902
...Noise
990
STF
704
LTF
706
SIG
708
Data
710
ANT0
ANT1
ANT2
ANT0
(Detect)
ANT1
ANT2
ANT0
T_stf
991
992
993
994
995
996
997

FIG. 9

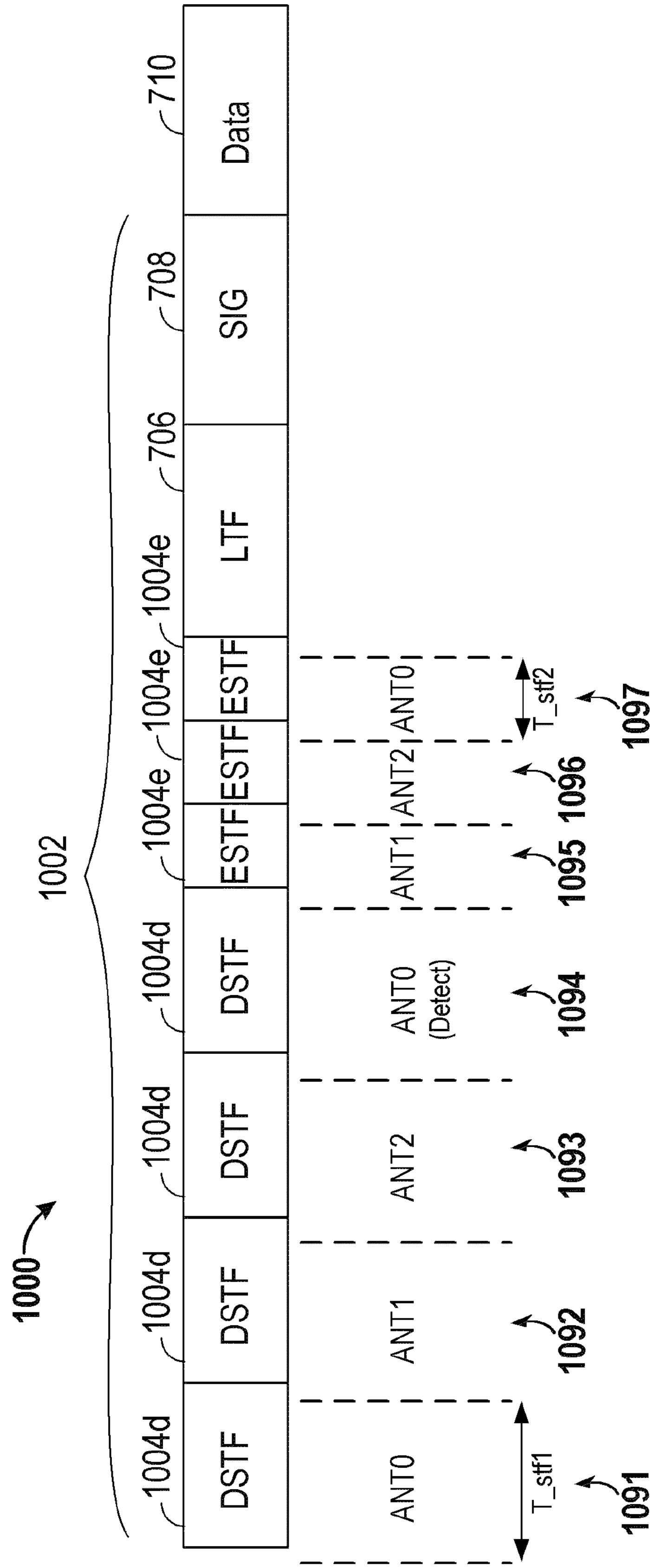

1000
1002
DSTF
DSTF
DSTF
DSTF
ESTF
ESTF
ESTF
LTF
SIG
Data
1004d
1004d
1004d
1004d
1004e
1004e
1004e
1004e
706
708
710
ANT0
ANT1
ANT2
ANT0
(Detect)
ANT1
ANT2
ANT0
T_stf1
T_stf2
1091
1092
1093
1094
1095
1096
1097

FIG. 10

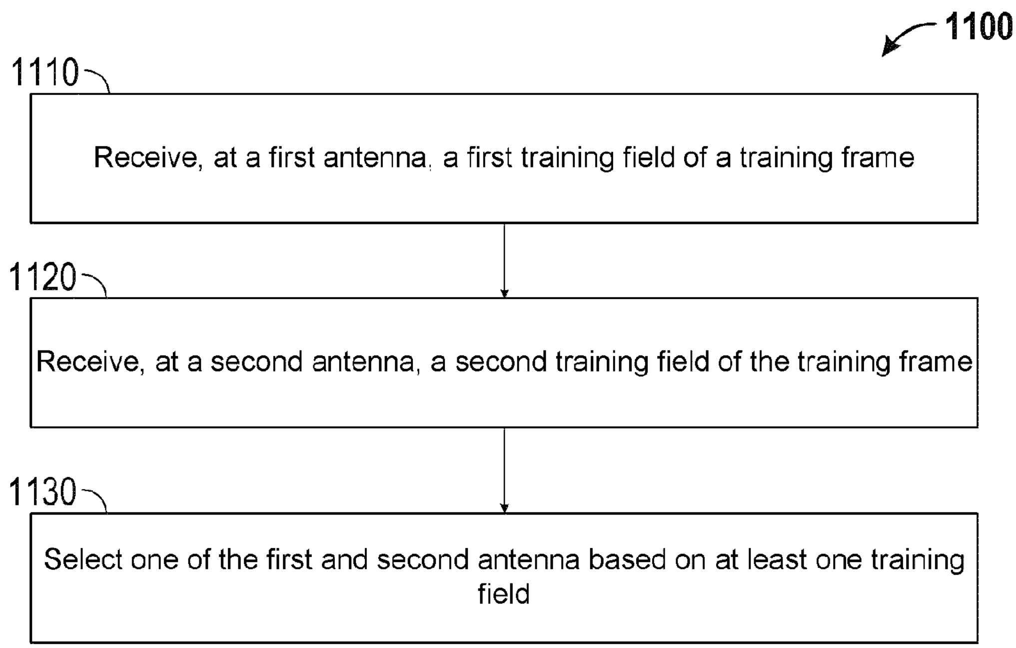

1100
1110
Receive, at a first antenna, a first training field of a training frame
1120
Receive, at a second antenna, a second training field of the training frame
1130
Select one of the first and second antenna based on at least one training field

FIG. 11

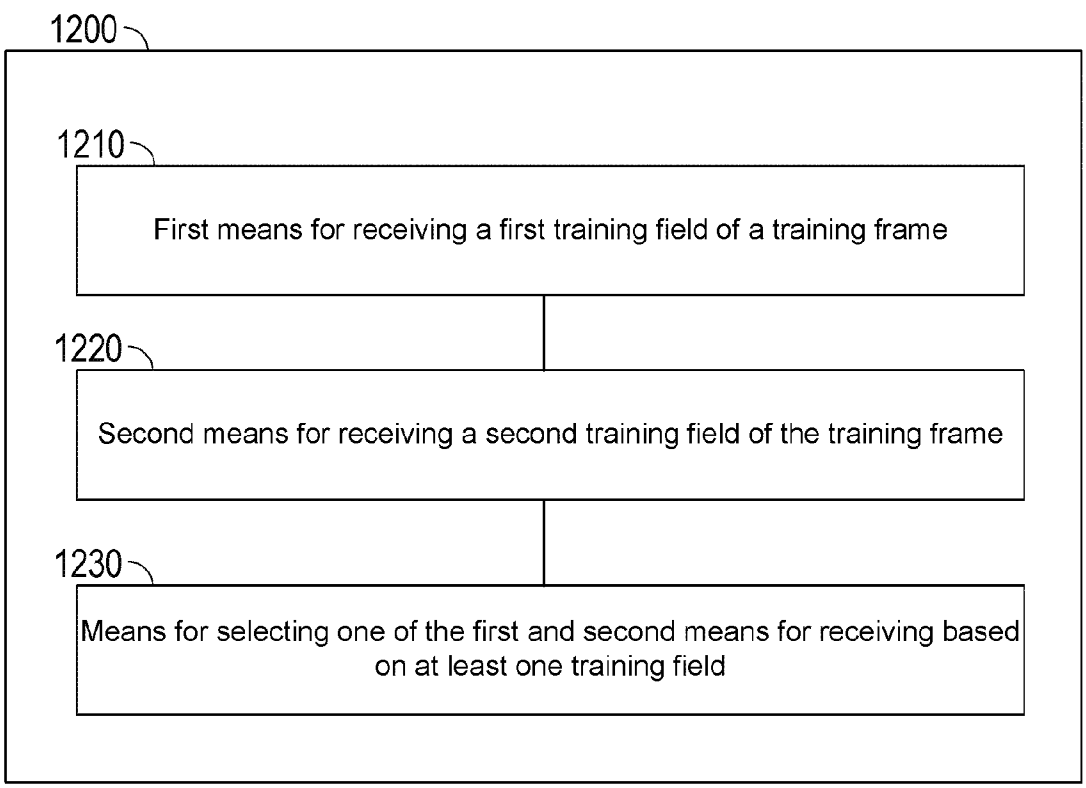

1200
1210
First means for receiving a first training field of a training frame
1220
Second means for receiving a second training field of the training frame
1230
Means for selecting one of the first and second means for receiving based on at least one training field

FIG. 12

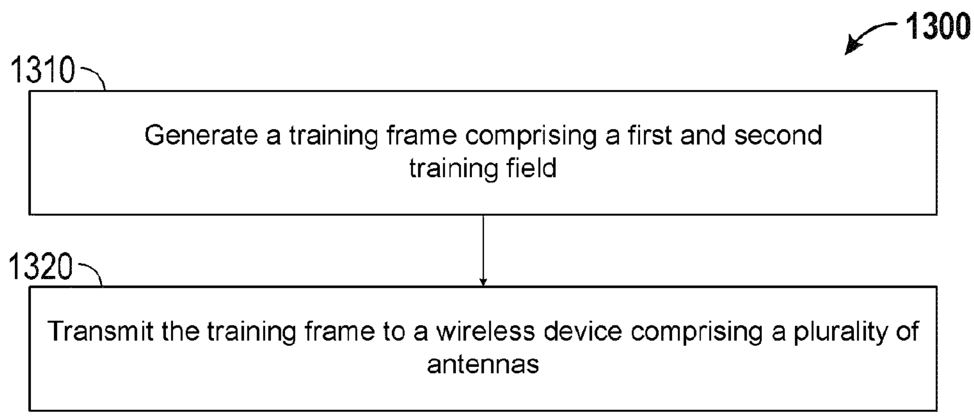

1300
1310
Generate a training frame comprising a first and second training field
1320
Transmit the training frame to a wireless device comprising a plurality of antennas

FIG. 13

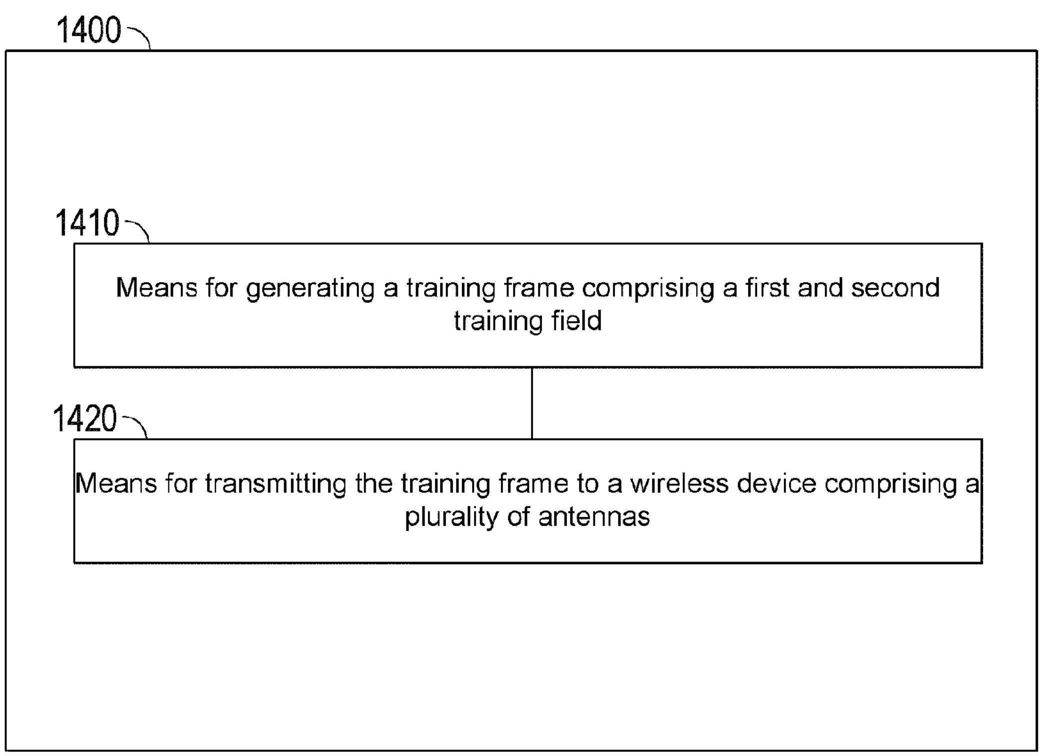

1400
1410
Means for generating a training frame comprising a first and second training field
1420
Means for transmitting the training frame to a wireless device comprising a plurality of antennas

FIG. 14

APPARATUS AND METHODS FOR WIRELESS COMMUNICATION IN POWER-RESTRICTED FREQUENCY BANDS

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application claims priority to provisional U.S. Application Ser. No. 61/701,539, entitled "Apparatus and Methods for Wireless Communication in Power-Restricted Frequency Bands," filed Sep. 14, 2012, assigned to the assignee hereof and incorporated herein by reference in its entirety.

FIELD

The present application relates generally to wireless communications, and specifically to systems, methods, and devices to enable wireless communication in power-restricted frequency bands. Certain aspects herein relate to antenna selection in orthogonal frequency-division multiplexing (OFDM) communications.

BACKGROUND

In many telecommunication systems, communications networks are used to exchange messages among several interacting spatially-separated devices. Networks may be classified according to geographic scope, which could be, for example, a metropolitan area, a local area, a personal area, or a broad area that links multiple boundaries. Such networks may be designated respectively as metropolitan area network (MAN), local area network (LAN), personal area network (PAN), or wide area network (WAN). Networks also differ according to the switching or routing technique used to interconnect the various network nodes and devices (e.g., circuit switching vs. packet switching), the type of physical media employed for transmission (e.g., wired vs. wireless), and the set of communication protocols used (e.g., Internet protocol suite, SONET (Synchronous Optical Networking), Ethernet, etc.).

Wireless networks are often preferred when the network elements are mobile with dynamic connectivity needs or if the network architecture is formed in an ad hoc, rather than fixed, topology. Wireless networks employ intangible physical media in an unguided propagation mode using electromagnetic waves in the radio, microwave, infra-red, optical, etc. frequency bands. When compared to fixed wired networks, wireless networks advantageously facilitate user mobility and rapid field deployment.

The devices in a wireless network may transmit or receive information between each other. The information may include packets, which may be referred to as data units. The packets may include overhead information (e.g., headers, packet properties, etc.) that helps in routing the packet through the network, identifying the data in the packet, processing the packet, etc. The packets may also include data, such as user information, multimedia content, etc.

SUMMARY

The systems, methods, and devices of the invention each have several aspects, no single one of which is solely responsible for its desirable attributes. Without limiting the scope of this invention as expressed by the claims which follow, some features will now be discussed briefly. After considering this discussion, and particularly after reading the section entitled

"Detailed Description," one will understand how the features of this invention provide advantages, e.g., antenna selection and wireless communication in power-restricted frequency bands.

One aspect of the subject matter described in the disclosure provides a method of selecting one of a plurality of antennas. The method includes receiving, at a first antenna, a first training field of a training frame. The method further includes receiving, at a second antenna, a second training field of the training frame. The method further includes selecting one of the first and second antennas based on at least one training field.

Another aspect of the subject matter described in the disclosure provides a method of wireless communication. The method includes generating a training frame including a first and second training field. The method further includes transmitting the training frame to a wireless device including a plurality of antennas. The training frame includes a number of training fields equal to or greater than two times the number of the plurality of antennas.

Another aspect of the subject matter described in the disclosure provides a wireless device configured to select one of a plurality of antennas. The device includes a first antenna configured to receive a first training field of a training frame. The device further includes a second antenna configured to receive a second training field of the training frame. The device further includes a processor configured to select one of the first and second antenna based on at least one training field.

Another aspect of the subject matter described in the disclosure provides a device configured to communicate wirelessly. The device includes a processor configured to generate a training frame including a first and second training field. The device further includes a transmitter configured to transmit the training frame to a wireless device including a plurality of antennas. The training frame includes a number of training fields equal to or greater than two times the number of the plurality of antennas.

Another aspect of the subject matter described in the disclosure provides an apparatus for wireless communication. The apparatus includes first means for receiving a first training field of a training frame. The apparatus further includes second means for receiving a second training field of the training frame. The apparatus further includes means for selecting one of the first and second means for receiving, based on at least one training field.

Another aspect of the subject matter described in the disclosure provides an apparatus for wireless communication. The apparatus includes means for generating a training frame including a first and second training field. The apparatus further includes means for transmitting the training frame to a wireless device including a plurality of antennas. The training frame includes a number of training fields equal to or greater than two times the number of the plurality of antennas.

Another aspect of the subject matter described in the disclosure provides a non-transitory computer-readable medium including code that, when executed, causes an apparatus to receive, at a first antenna, a first training field of a training frame. The medium further includes code that, when executed, causes the apparatus to receive, at a second antenna, a second training field of the training frame. The medium further includes code that, when executed, causes the apparatus to select one of the first and second antenna based on at least one training field.

Another aspect of the subject matter described in the disclosure provides a non-transitory computer-readable medium including code that, when executed, causes an apparatus to generate a training frame including a first and second training field. The medium further includes code that, when executed, causes the apparatus to transmit the training frame to a wireless device including a plurality of antennas. The training frame includes a number of training fields equal to or greater than two times the number of the plurality of antennas.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates an example of a wireless communication system in which aspects of the present disclosure may be employed.

FIG. **2** shows a functional block diagram of an exemplary wireless device that may be employed within the wireless communication system of FIG. **1**.

FIG. **3** shows a functional block diagram of exemplary components that may be utilized in the wireless device of FIG. **2** to transmit wireless communications.

FIG. **4** shows a functional block diagram of exemplary components that may be utilized in the wireless device of FIG. **2** to receive wireless communications, according to an embodiment.

FIG. **5** is a functional block diagram of an exemplary MIMO system that may be implemented in wireless devices such as the wireless device of FIG. **2** to transmit wireless communications.

FIG. **6** is a functional block diagram of an exemplary MIMO system that may be implemented in wireless devices such as the wireless device of FIG. **2** to receive wireless communications.

FIG. **7** is a block diagram showing an exemplary structure of a preamble and payload of a physical layer packet.

FIG. **8** illustrates various components that may be utilized in the wireless device to receive wireless communications, according to another embodiment.

FIG. **9** is a block diagram showing another exemplary structure of a preamble and payload of a physical layer packet.

FIG. **10** is a block diagram showing another exemplary structure of a preamble and payload of a physical layer packet.

FIG. **11** is a flowchart of an exemplary method of selecting one of a plurality of antennas.

FIG. **12** is a functional block diagram of an apparatus for wireless communication, in accordance with an exemplary embodiment of the invention.

FIG. **13** is a flowchart of an exemplary method of wireless communication.

FIG. **14** is a functional block diagram of an apparatus for wireless communication, in accordance with an exemplary embodiment of the invention.

DETAILED DESCRIPTION

Various aspects of the novel systems, apparatuses, and methods are described more fully hereinafter with reference to the accompanying drawings. The teachings disclosure may, however, be embodied in many different forms and should not be construed as limited to any specific structure or function presented throughout this disclosure. Rather, these aspects are provided so that this disclosure will be thorough and complete and will fully convey the scope of the disclosure to those skilled in the art. Based on the teachings herein, one skilled in the art should appreciate that the scope of the disclosure is intended to cover any aspect of the novel systems, apparatuses, and methods disclosed herein, whether implemented independently of or combined with any other aspect of the invention. For example, an apparatus may be implemented or a method may be practiced using any number of the aspects set forth herein. In addition, the scope of the invention is intended to cover such an apparatus or method which is practiced using other structure, functionality, or structure and functionality in addition to or other than the various aspects of the invention set forth herein. It should be understood that any aspect disclosed herein may be embodied by one or more elements of a claim.

Although particular aspects are described herein, many variations and permutations of these aspects fall within the scope of the disclosure. Although some benefits and advantages of the preferred aspects are mentioned, the scope of the disclosure is not intended to be limited to particular benefits, uses, or objectives. Rather, aspects of the disclosure are intended to be broadly applicable to different wireless technologies, system configurations, networks, and transmission protocols, some of which are illustrated by way of example in the figures and in the following description of the preferred aspects. The detailed description and drawings are merely illustrative of the disclosure, rather than limiting, the scope of the disclosure being defined by the appended claims and equivalents thereof.

Wireless network technologies may include various types of wireless local area networks (WLANs). A WLAN may be used to interconnect nearby devices together, employing widely used networking protocols. The various aspects described herein may apply to any communication standard, such as WiFi or, more generally, any member of the IEEE 802.11 family of wireless protocols. For example, the various aspects described herein may be used as part of the IEEE 802.11ac protocol. The communication standard can include an ultra-wideband (UWB) standard.

In some aspects, wireless signals in a 6-9 GHz band may be transmitted using orthogonal frequency-division multiplexing (OFDM), direct-sequence spread spectrum (DSSS) communications, a combination of OFDM and DSSS communications, or other schemes. Implementations may be used in applications where transmit power is restricted, such as, for example, short-range wireless personal area network (WPAN) communications. Advantageously, aspects of certain devices may consume less power than devices implementing other wireless protocols and/or may be used to transmit wireless signals within relatively low transmit power rules, regulations, or restrictions.

In some implementations, a WLAN includes various devices which are the components that access the wireless network. For example, there may be two types of devices: access points ("APs") and clients (also referred to as stations, or "STAs"). In general, an AP serves as a hub or base station for the WLAN and an STA serves as a user of the WLAN. For example, an STA may be a laptop computer, a personal digital assistant (PDA), a mobile phone, etc. An STA could connect to an AP via a WiFi (e.g., IEEE 802.11 protocol such as 802.11ac) compliant wireless link to obtain connectivity to the Internet or to other wide area networks. In some implementations, an STA may also be used as an AP.

An access point ("AP") may also include, be implemented as, or known as a NodeB, Radio Network Controller ("RNC"), eNodeB, Base Station Controller ("BSC"), Base Transceiver Station ("BTS"), Base Station ("BS"), Transceiver Function ("TF"), Radio Router, Radio Transceiver, or some other terminology.

A station "STA" may also include, be implemented as, or known as an access terminal ("AT"), a subscriber station, a subscriber unit, a mobile station, a remote station, a remote terminal, a user terminal, a user agent, a user device, user equipment, or some other terminology. In some implementations, an access terminal may include a cellular telephone, a cordless telephone, a Session Initiation Protocol ("SIP") phone, a wireless local loop ("WLL") station, a personal digital assistant ("PDA"), a handheld device having wireless connection capability, or some other suitable processing device connected to a wireless modem. Accordingly, one or more aspects taught herein may be incorporated into a phone (e.g., a cellular phone or smartphone), a computer (e.g., a laptop), a portable communication device, a headset, a portable computing device (e.g., a personal data assistant), an entertainment device (e.g., a music or video device, or a satellite radio), a gaming device or system, a global positioning system ("GPS") device, or any other suitable device that is configured to communicate via a wireless medium.

As discussed above, certain of the devices described herein may implement an 802.11 standard. Such devices, whether used as an STA, AP, or other device, may be used for smart metering or in a smart grid network. Such devices may provide sensor applications or be used in home automation. The devices may instead or in addition be used in a healthcare context, e.g., for personal healthcare. They may also be used for surveillance, to enable extended-range Internet connectivity (e.g., for use with hotspots), or to implement machine-to-machine communications.

Certain of the devices described herein may further implement Multiple Input Multiple Output (MIMO) technology and be implemented as part of the 802.11 standard. A MIMO system employs multiple (N_T) transmit antennas and multiple (N_R) receive antennas for data transmission. A MIMO channel formed by the N_T transmit and N_R receive antennas may be decomposed into N_S independent channels, i.e., spatial channels or streams, where $N_S \leq \min\{N_T, N_R\}$. Each of the N_S independent channels corresponds to a dimension. The MIMO system can provide improved performance (e.g., higher throughput and/or greater reliability) if the additional dimensionalities created by the multiple transmit and receive antennas are utilized.

FIG. **1** illustrates an example of a wireless communication system **100** in which aspects of the present disclosure may be employed. The wireless communication system **100** may operate pursuant to a wireless standard, for example the 802.11ac standard. The wireless communication system **100** may include an AP **104**, which communicates with STAs **106**.

A variety of processes and methods may be used for transmissions in the wireless communication system **100** between the AP **104** and the STAs **106**. For example, signals may be sent and received between the AP **104** and the STAs **106** in accordance with OFDM/OFDMA techniques. If this is the case, the wireless communication system **100** may be referred to as an OFDM/OFDMA system. As another example, signals may be sent and received between the AP **104** and the STAs **106** in accordance with CDMA techniques. If this is the case, the wireless communication system **100** may be referred to as a CDMA system.

A communication link that facilitates transmission from the AP **104** to one or more of the STAs **106** may be referred to as a downlink (DL) **108**, and a communication link that facilitates transmission from one or more of the STAs **106** to the AP **104** may be referred to as an uplink (UL) **110**. Alternatively, a downlink **108** may be referred to as a forward link or a forward channel, and an uplink **110** may be referred to as a reverse link or a reverse channel.

The AP **104** may act as a base station and provide wireless communication coverage in a basic service area (BSA) **102**. The AP **104** along with the STAs **106** associated with the AP **104** and that use the AP **104** for communication may be referred to as a basic service set (BSS). It should be noted that the wireless communication system **100** may not have a central AP **104**, but rather may function as a peer-to-peer network between the STAs **106**. Accordingly, the functions of the AP **104** described herein may alternatively be performed by one or more of the STAs **106**.

FIG. **2** illustrates various components that may be utilized in a wireless device **202** that may be employed within the wireless communication system **100**. The wireless device **202** is an example of a device that may be configured to implement the various methods described herein. For example, the wireless device **202** may include the AP **104** or one of the STAs **106**.

The wireless device **202** may include a processor **204** which controls operation of the wireless device **202**. The processor **204** may also be referred to as a central processing unit (CPU). Memory **206**, which may include both read-only memory (ROM) and random access memory (RAM), provides instructions and data to the processor **204**. A portion of the memory **206** may also include non-volatile random access memory (NVRAM). The processor **204** typically performs logical and arithmetic operations based on program instructions stored within the memory **206**. The instructions in the memory **206** may be executable to implement the methods described herein.

The processor **204** may include or be a component of a processing system implemented with one or more processors. The one or more processors may be implemented with any combination of general-purpose microprocessors, microcontrollers, digital signal processors (DSPs), field programmable gate array (FPGAs), programmable logic devices (PLDs), controllers, state machines, gated logic, discrete hardware components, dedicated hardware finite state machines, or any other suitable entities that can perform calculations or other manipulations of information.

The processing system may also include machine-readable media for storing software. Software shall be construed broadly to mean any type of instructions, whether referred to as software, firmware, middleware, microcode, hardware description language, or otherwise. Instructions may include code (e.g., source code, binary code, executable code, or any other suitable code format). The instructions, when executed by the one or more processors, cause the processing system to perform the various functions described herein.

The wireless device **202** may also include a housing **208** that may include a transmitter **210** and a receiver **212** to allow transmission and reception of data between the wireless device **202** and a remote location. The transmitter **210** and receiver **212** may be combined into a transceiver **214**. An antenna **216** may be attached to the housing **208** and electrically coupled to the transceiver **214**. The wireless device **202** may also include (not shown) multiple transmitters, multiple receivers, multiple transceivers, and/or multiple antennas.

The wireless device **202** may also include a signal detector **218** that may be used in an effort to detect and quantify the level of signals received by the transceiver **214**. The signal detector **218** may detect such signals as total energy, energy per subcarrier per symbol, power spectral density, and other signals. The wireless device **202** may also include a digital signal processor (DSP) **220** for processing signals. The DSP **220** may be configured to generate a data unit for transmission. In some aspects, the data unit may include a physical layer data unit (PPDU). In some aspects, the PPDU is referred to as a packet.

The wireless device **202** may further include a user interface **222** in some aspects. The user interface **222** may include a keypad, a microphone, a speaker, a display, or any other element or component that conveys information to a user of the wireless device **202** or receives input from the user.

The various components of the wireless device **202** may be coupled together by a bus system **226**. The bus system **226** may include a data bus, for example, as well as a power bus, a control signal bus, and a status signal bus. Those of skill in the art will appreciate that the components of the wireless device **202** may be coupled together or accept or provide inputs to each other using some other mechanism.

Although a number of separate components are illustrated in FIG. **2**, those of skill in the art will recognize that one or more of the components may be combined or commonly implemented. For example, the processor **204** may be used to implement not only the functionality described above with respect to the processor **204**, but also to implement the functionality described above with respect to the signal detector **218** and/or the DSP **220**. Further, each of the components illustrated in FIG. **2** may be implemented using a plurality of separate elements. Furthermore, the processor **204** may be used to implement any of the components, modules, circuits, or the like described below, or each may be implemented using a plurality of separate elements.

As discussed above, the wireless device **202** may include an AP **104** or an STA **106**, and may be used to transmit and/or receive communications. FIG. **3** illustrates various components that may be utilized in the wireless device **202** to transmit wireless communications. The components illustrated in FIG. **3** may be used, for example, to transmit OFDM communications. In some aspects, the components illustrated in FIG. **3** are used to generate and transmit packets having an adjustable preamble, as will be discussed in additional detail below. For ease of reference, the wireless device **202** configured with the components illustrated in FIG. **3** is hereinafter referred to as a wireless device **302***a*.

The wireless device **302***a* may include a modulator **302** configured to modulate bits for transmission. For example, the modulator **302** may determine a plurality of symbols from bits received from the processor **204** (FIG. **2**) or the user interface **222** (FIG. **2**), for example, by mapping bits to a plurality of symbols according to a constellation. The bits may correspond to user data or to control information. In some aspects, the bits are received in codewords. In one aspect, the modulator **302** includes a QAM (quadrature amplitude modulation) modulator, such as a 16-QAM modulator or a 64-QAM modulator. In other aspects, the modulator **302** includes a binary phase-shift keying (BPSK) modulator or a quadrature phase-shift keying (QPSK) modulator.

The wireless device **302***a* may further include a transform module **304** configured to convert symbols or otherwise modulated bits from the modulator **302** into a time domain. In FIG. **3**, the transform module **304** is illustrated as being implemented by an inverse fast Fourier transform (IFFT) module. In some implementations, there may be multiple transform modules (not shown) that transform units of data of different sizes. In some implementations, the transform module **304** may be itself configured to transform units of data of different sizes. For example, the transform module **304** may be configured with a plurality of modes, and it may use a different number of points to convert the symbols in each mode. For example, the IFFT may have a mode where 256 points are used to convert symbols being transmitted over 256 tones (i.e., subcarriers) into a time domain, a mode where 512 points are used to convert symbols being transmitted over 512 tones into a time domain, and/or a mode where 1,024 points are used to convert symbols being transmitted over 1,024 tones into a time domain. The number of points used by the transform module **304** may be referred to as the size of the transform module **304**.

In FIG. **3**, the modulator **302** and the transform module **304** are illustrated as being implemented in the DSP **320**. In some aspects, however, one or both of the modulator **302** and the transform module **304** are implemented in the processor **204** or in another element of the wireless device **302***a* (e.g., see description above with reference to FIG. **2**).

As discussed above, the DSP **320** may be configured to generate a data unit for transmission. In some aspects, the modulator **302** and the transform module **304** may be configured to generate a data unit including a plurality of fields including control information and a plurality of data symbols. The fields including the control information may include one or more training fields (e.g., short training fields), for example, and one or more signal (SIG) fields. Each of the training fields may include a known sequence of values or symbols (e.g., shorts). Each of the SIG fields may include information about the data unit, for example, a description of a length or data rate of the data unit.

Returning to the description of FIG. **3**, the wireless device **302***a* may further include a digital to analog converter **306** configured to convert the output of the transform module into an analog signal. For example, the time-domain output of the transform module **306** may be converted to a baseband OFDM signal by the digital to analog converter **306**. The digital to analog converter **306** may be implemented in the processor **204** or in another element of the wireless device **202**. In some aspects, the digital to analog converter **306** is implemented in the transceiver **214** (FIG. **2**) or in a data transmit processor.

The analog signal may be wirelessly transmitted by the transmitter **310**. The analog signal may be further processed before being transmitted by the transmitter **310**, for example, by being filtered or by being upconverted to an intermediate or carrier frequency. In the aspect illustrated in FIG. **3**, the transmitter **310** includes a transmit amplifier **308**. Prior to being transmitted, the analog signal may be amplified by the transmit amplifier **308**. In some aspects, the transmit amplifier **308** includes a low-noise amplifier (LNA) (not pictured).

The transmitter **310** is configured to transmit one or more packets or data units in a wireless signal based on the analog signal. The data units may be generated using the processor **204** (FIG. **2**) and/or the DSP **320**, for example, using the modulator **302** and the transform module **304** as discussed above. The data units that may be generated and transmitted are described in additional detail below with respect to FIGS. **5-14**.

FIG. **4** illustrates various components that may be utilized in the wireless device **202** to receive wireless communications, according to an embodiment. The components illustrated in FIG. **4** may be used, for example, to receive OFDM communications. In some aspects, the components illustrated in FIG. **4** are used to receive data units having an adjustable preamble, as will be discussed in additional detail below. For example, the components illustrated in FIG. **4** may be used to receive data units transmitted by the components discussed above with respect to FIG. **3**. For ease of reference, the wireless device **202** configured with the components illustrated in FIG. **4** is hereinafter referred to as a wireless device **402***b*.

The receiver **412** is configured to receive one or more packets or data units in a wireless signal. Data units that may be received and decoded or otherwise processed as discussed below are described in additional detail with respect to FIGS. **5-14**.

In the aspect illustrated in FIG. **4**, the receiver **412** includes a receive amplifier **401**. The receive amplifier **401** may be configured to amplify the wireless signal received by the receiver **412**. In some aspects, the receiver **412** is configured to adjust the gain of the receive amplifier **401** using an automatic gain control (AGC) procedure. In some aspects, the automatic gain control uses information in one or more received training fields, such as a received short training field (STF) for example, to adjust the gain. Those having ordinary skill in the art will understand methods for performing AGC. In some aspects, the amplifier **401** includes a low-noise amplifier (LNA).

The wireless device **402***b* may include an analog to digital converter **410** configured to convert the amplified wireless signal from the receiver **412** into a digital representation thereof. The wireless signal may also be processed by the analog to digital converter **410** before being converted, for example, by being filtered or by being downconverted to an intermediate or baseband frequency. The analog to digital converter **410** may be implemented in the processor **204** (FIG. **2**) or in another element of the wireless device **402***b*. In some aspects, the analog to digital converter **410** is implemented in the transceiver **214** (FIG. **2**) or in a data receive processor.

The wireless device **402***b* may further include a transform module **404** configured to convert the representation of the wireless signal into a frequency spectrum. In FIG. **4**, the transform module **404** is illustrated as being implemented by a fast Fourier transform (FFT) module. As described above with reference to FIG. **3**, the transform module **404** may be configured with a plurality of modes and may use a different number of points to convert the signal in each mode. For example, the transform module **404** may have a mode where 256 points are used to convert a signal received over 256 tones into a frequency spectrum, a mode where 512 points are used to convert a signal received over 512 tones into a frequency spectrum, and/or a mode where 1,024 points are used to convert a signal received over 1,024 tones into a frequency spectrum. The number of points used by the transform module **404** may be referred to as the size of the transform module **404**. In some aspects, the transform module **404** may identify a symbol for each point that it uses.

The wireless device **402***b* may further include a channel estimator and equalizer **405** configured to form an estimate of the channel over which the data unit is received and to remove certain effects of the channel based on the channel estimate. For example, the channel estimator **405** may be configured to approximate a function of the channel, and the channel equalizer may be configured to apply an inverse of that function to the data in the frequency spectrum.

In some aspects, the channel estimator and equalizer **405** uses information in one or more received training fields, such as a long training field (LTF), to estimate the channel. The channel estimate may be formed based on one or more LTFs received at the beginning of the data unit. This channel estimate may thereafter be used to equalize data symbols that follow the one or more LTFs. After a certain period of time or after a certain number of data symbols, one or more additional LTFs may be received in the data unit. The channel estimate may be updated or a new estimate formed using the additional LTFs. This new or updated channel estimate may be used to equalize data symbols that follow the additional LTFs. In some aspects, the new or updated channel estimate is used to re-equalize data symbols preceding the additional LTFs. Those having ordinary skill in the art will understand methods for forming a channel estimate.

The wireless device **402***b* may further include a demodulator **406** configured to demodulate the equalized data. For example, the demodulator **406** may determine a plurality of bits from symbols output by the transform module **404** and the channel estimator and equalizer **405**, for example, by reversing a mapping of bits to a symbol in a constellation. The bits may be processed or evaluated by the processor **204** (FIG. **2**) or used to display or otherwise output information to the user interface **222** (FIG. **2**). In this way, data and information may be decoded. In some aspects, the bits correspond to codewords. In one aspect, the demodulator **406** includes a QAM (quadrature amplitude modulation) demodulator, e.g., a 16-QAM demodulator or a 64-QAM demodulator. In other aspects, the demodulator **406** includes a binary phase-shift keying (BPSK) demodulator or a quadrature phase-shift keying (QPSK) demodulator.

In FIG. **4**, the transform module **404**, the channel estimator and equalizer **405**, and the demodulator **406** are illustrated as being implemented in a DSP **420**. In some aspects, however, one or more of the transform module **404**, the channel estimator and equalizer **405**, and the demodulator **406** are implemented in the processor **204** (FIG. **2**) or in another element of the wireless device **202** (FIG. **2**).

As discussed above, the wireless signal received at the receiver **212** includes one or more data units. Using the functions or components described above, the data units or data symbols therein may be decoded, evaluated, or otherwise processed. For example, the processor **204** (FIG. **2**) and/or the DSP **420** may be used to decode data symbols in the data units using the transform module **404**, the channel estimator and equalizer **405**, and the demodulator **406**.

Data units exchanged by the AP **104** and the STA **106** may include control information or data, as discussed above. At the physical (PHY) layer, these data units may be referred to as physical layer protocol data units (PPDUs). In some aspects, a PPDU may be referred to as a packet or physical layer packet. Each PPDU may include a preamble and a payload. The preamble may include training fields and a SIG field. The payload may include a Media Access Control (MAC) header or data for other layers, and/or user data, for example. The payload may be transmitted using one or more data symbols. The systems, methods, and devices herein may utilize data units with training fields whose peak-to-power ratio has been minimized.

The wireless device **302***a* shown in FIG. **3** shows an example of a single transmit chain to be transmitted over an antenna. In some implementations, the wireless device **302***a* may implement a portion of a MIMO system using multiple antennas to simultaneously transmit data.

FIG. **5** is a functional block diagram of a MIMO system that may be implemented in wireless devices such as the wireless device **202** of FIG. **2** to transmit and receive wireless communications. The MIMO system may make use of some or all of the components described with reference to FIG. **3**. Bits for transmission that are to be received at an output of the receiver are provided to an encoder **504**. The encoder **504** may apply a forward error correcting (FEC) code on the bit stream. The FEC code may be a block code, a convolutional code, or the like. The encoded bits are provided to an interleaving system **505** that distributes the encoded bits into N transmit streams.

The interleaving system **505** includes a stream parser **506** that parses an input bit stream from the encoder **504** to N spatial stream interleavers **508***a*, **508***b*, and **508***n*. The stream parser **506** may be provided with the number of spatial streams and parse bits on a round-robin basis. Other parsing functions may also be used. One parsing function that may be used is $k_n = N_{TX} * k + n$ (i.e., round-robin with one bit per spatial stream, then on to the next spatial stream where is the input bit index and N_{TX} is the number of transmitters/spatial streams). Another more general function f(k,n) might also be used, for example, sending two bits to a spatial stream, then moving on to the next spatial stream. Each interleaver **508***a*, **508***b*, and **508***n* may each thereafter distribute bits so that errors may be recovered due to fading or other channel conditions. Hereinafter, the interleavers **508***a*, **508***b*, and **508***n* may be referred to as interleaver **508**.

Each transmit stream may then be modulated by a modulator **502***a*, **502***b*, or **502***n*. As described above with reference to FIG. **3**, the bits may be modulated using modulation techniques such as QPSK (Quaternary Phase Shift Keying) modulation, BPSK (mapping one bit at a time), 16-QAM (mapping groups of six bits), 64-QAM, and the like. The modulated bits for each stream may be provided to transform modules **510***a*, **510***b*, and **510***n*. In some implementations, the transform modules **510***a*, **510***b*, and **510***n* may perform an inverse discrete time Fourier transform (IDFT) to convert the modulated bits from a frequency domain into a time domain. The transform modules **510***a*, **510***b*, and **510***n* may operate according to different modes as described above with reference to FIG. **3**. For example, the transform modules **510***a*, **510***b*, and **510***n* may be configured to operate according to a 256 point mode, a 512 point mode, and/or a 1,024 point mode. In some implementations, the modulated bits may be encoded using space time block coding (STBC) and spatial mapping may be performed before being provided to transform modules **510***a*, **510***b*, and **510***n*. After the modulated bits have been converted into time domain signals for each spatial stream, the time domain signal may be converted into an analog signal via converters **512***a*, **512***b*, and **512***n* as described above with reference to FIG. **3**. The signals may then be transmitted using transmitters **514***a*, **514***b*, or **514***c* and using antennas **516***a*, **516***b*, or **516***n*, into a wireless radio space over a desired frequency bandwidth (e.g., 1 MHz, 2 MHz, 4 MHz, 8 MHz, and 16 MHz, or higher).

In some embodiments, antennas **516***a*, **516***b*, and **516***n* are distinct and spatially separated antennas. In other embodiments, distinct signals might be combined into different polarizations off of fewer than N antennas. An example of this is where spatial rotation or spatial spreading is done, where multiple spatial streams are mapped on a single antenna. In any case, it should be understood that distinct spatial streams can be organized in different manners. For example, a transmit antenna might carry data from more than one spatial stream or several transmit antennas might carry data from a single spatial stream. For example, consider the case of a transmitter with four transmit antennas and two spatial streams. Each spatial stream can be mapped onto two transmit antennas in that case, so two antennas are carrying data from just one spatial stream.

FIG. **6** is a functional block diagram of an exemplary MIMO system that may be implemented in wireless devices such as the wireless device **202** of FIG. **2** to receive wireless communications. The wireless device **202***b* may be configured to simultaneously receive transmissions from the antennas **516***a*, **516***b*, and **516***n* of FIG. **5**. A wireless device **202***b* receives signals from the channel at N antennas **518***a*, **518***b*, and **518***n* (counting separate polarizations, as appropriate) coupled to N receive circuits. The signals are then provided to receivers **620***a*, **620***b*, and **620***n* that each may include an amplifier configured to amplify the received signals. The signals may then be converted into a digital form via converters **622***a*, **622***b*, and **622***n*.

Converted signals may then be converted into a frequency spectrum via transform modules **624***a*, **624***b*, and **624***n*. As described above, the transform modules **624***a*, **624***b*, and **624***n* may operate according to various modes according to the size and bandwidth used (e.g., 256 point, 512 point, 1,024 point, etc.). The transformed signals may be provided to respective channel estimator and equalizer blocks **626***a*, **626***b*, and **626***n* that may function similarly as described above with reference to FIG. **4**. After channel estimation, the outputs may be provided to a MIMO detector **628**, which may thereafter provide its output to demodulators **630***a*, **630***b*, and **630***n*, which may demodulate the bits according to one of the modulation techniques as described above. Demodulated bits may then be provided to deinterleavers **632***a*, **632***b*, and **632***n*, which may pass bits into a stream de-parser **634**, which may provide the bits into a single bit stream into a decoder **636** that may decode the bits into an appropriate data stream.

As described above, data units exchanged by the AP **104** and the STA **106** may include control information or data in the form of physical (PHY) layer packets or physical layer protocol data units (PPDUs).

FIG. **7** is a block diagram showing an exemplary structure of a preamble **702** and payload **710** of a physical layer packet **700**. The preamble **702** may include a short training field (STF) **704** that includes an STF sequence of known values (referred to herein as a "short"). In some aspects, the STF may be used for packet detection (e.g., to detect the start of a packet), receive power estimation, antenna selection, and for coarse time/frequency estimation. The STF sequence may be optimized to have a low peak-to-average power ratio ("PAPR") and include a subset of non-zero tones with a particular periodicity. The STF **704** may span one or multiple OFDM symbols. In some embodiments, the STF **704** can include multiple repeated STF sequences ("shorts"). For example, the STF **704** can include between around 1-20 shorts, and more particularly around 10 shorts.

The preamble **702** may further include a long training field (LTF) **706** that may span one or more OFDM symbols and may include one or more LTF sequences of known, non-zero values. The LTF may be used for channel estimation, fine time/frequency estimation, and mode detection. The preamble **702** may further include a signal field (SIG) **708** as described above that may include a number of bits or values used in one aspect for mode detection purposes and determination of transmission parameters.

As discussed above, various aspects described herein can be used for wireless communication in a power-limited frequency band. For example, rules, regulations, or standards may limit an allowed transmit power. Accordingly, received signal strength may be relatively weak. In certain aspects, a receiving device can include a plurality of antennas having receive diversity. The receiving device can select the antenna with the highest received signal strength. In determining the signal strength of each antenna, the receiving device can selectively connect each antenna to a single receive front-end. Including a single receive front-end for a set of multiple antennas can reduce the power consumption, area, and complexity of the receiver. However, if an antenna with poor reception is selected when a frame is transmitted to the receiver, the receiver may not detect the frame. In an embodiment, various aspects described herein can use an extended training preamble that can increase the likelihood that the receiving device will detect the frame.

FIG. **8** illustrates various components that may be utilized in the wireless device **202** to receive wireless communications, according to another embodiment. The components illustrated in FIG. **8** may be used, for example, to receive OFDM communications. In some aspects, the components illustrated in FIG. **8** are used to receive data units having an adjustable preamble, as will be discussed in additional detail below. For example, the components illustrated in FIG. **8** may be used to receive data units transmitted by the components discussed above with respect to FIG. **3**. For ease of reference, the wireless device **202** configured with the components illustrated in FIG. **8** is hereinafter referred to as a wireless device **802***b*.

In the illustrated embodiment, the wireless device **802***b* includes a receiver **812**, an analog-to-digital converter (ADC) **810**, an antenna switch **817**, a plurality of antennas **818***a*-**818***n*, a receive finite impulse response (RxFIR) filter **830**, a frame detector **840**, a received signal strength indication (RSSI) calculator **850**, and an automatic gain control **860**.

In an embodiment, the antennas **818***a*-**818***n* can have a mutual receive diversity. In other words, one or more of the antennas **818***a*-**818***n* can have a different configuration, e.g., a spatial location, an orientation, a tuning, a directionality, etc. For example, the antennas **818***a*-**818***n* can be arranged in a sectored pattern. In various embodiments, the antennas **818***a*-**818***n* can substitute for any other single antenna described herein. For example, one or more of the antennas **216** (FIG. **2**), **518***a*-**518***n* (FIG. **5**), and/or **618***a*-**618***n* (FIG. **6**) can each include an embodiment of the antennas **818***a*-**818***n* and the antenna switch **817** and can be used according to the methods described herein.

The antenna switch **817** serves to selectively connect the antennas **818***a*-**818***n* to the receive front-end and particularly to the amplifier **801** in the illustrated embodiment. In an embodiment, the antenna switch **817** can be controlled by the processor **204** (FIG. **2**) or dedicated selection circuitry (not shown) implementing one or more of the methods described herein. In some embodiments, the wireless device **802***b* can, for example, operate in a scanning or listening mode. In the scanning or listening mode, the wireless device **802***b* can listen for packets. The antenna switch **817** can switch between the antennas **818***a*-**818***n* using various methods, e.g., in a round-robin order, a random order, an order weighted by historical reception strength, etc. The antenna switch **817** can select each antenna **818***a*-**818***n* for the period of one STF **704** (FIGS. **7** and **9**), referred to herein as "T_stf."

The receiver **812** is configured to receive one or more packets or data units in a wireless signal. Data units that may be received and decoded or otherwise processed as discussed below are described in additional detail with respect to FIGS. **5**-**14**.

In the aspect illustrated in FIG. **8**, the receiver **812** includes a receive amplifier **801**. The receive amplifier **801** may be configured to amplify the wireless signal received by the receiver **812**. In some aspects, the receiver **812** is configured to adjust the gain of the receive amplifier **801** using an automatic gain control (AGC) procedure. In some aspects, the automatic gain control **860** uses information in one or more received training fields, such as a received short training field (STF) for example, to adjust the gain. Those having ordinary skill in the art will understand methods for performing AGC. In some aspects, the amplifier **801** includes an LNA. In an embodiment, when the wireless device **802***b* is in the scanning mode the AGC **860** can set the amplifier **801** to a maximum gain.

The wireless device **802***b* may include an analog to digital converter **810** configured to convert the amplified wireless signal from the receiver **812** into a digital representation thereof. Before being converted by the analog to digital converter **810**, the wireless signal may be processed, for example, by being filtered or by being downconverted to an intermediate or baseband frequency. The analog to digital converter **810** may be implemented in the processor **204** (FIG. **2**) or in another element of the wireless device **802***b*. In some aspects, the analog to digital converter **810** is implemented in the transceiver **214** (FIG. **2**) or in a data receive processor.

The RxFIR filter **830** serves to process the digitized signal from the ADC **820**. The RxFIR filter **830** can be implemented, for example, by the DSP **220** (FIG. **2**), the processor **204** (FIG. **2**), and/or the transform module **404** (FIG. **4**). The RSSI calculator **850** serves to estimate receive power for the selected antenna **818***a*-**818***n*. In some aspects, the RSSI calculator **850** uses information in one or more received training fields, such as a short training field (STF) for example, to estimate receive power. The RSSI calculator **850** can be implemented, for example, by the DSP **220** (FIG. **2**), the processor **204** (FIG. **2**), and/or the channel estimator **405** (FIG. **4**).

The detector **840** serves to detect a frame. For example, the detector **840** can be configured to trigger on the known pattern in the STF **704** (FIGS. **7** and **9**). Upon detection, the processor **204** (FIG. **2**) can cause the antenna switch **817** to select each antenna **818***a*-**818***n* in turn, and the RSSI calculator **850** can determine receive power estimates for each antenna **818***a*-**818***n*. In an embodiment, the antenna switch **817** can select each antenna **818***a*-**818***n* for about T_stf.

The antenna switch **817** can be configured to select the antenna **818***a*-**818***n* with the highest receive power estimate. The AGC **860** can set the antenna **818***a*-**818***n* gain at the amplifier **801**, based on the receive power estimate. In an embodiment, after the AGC **860** sets the antenna **818***a*-**818***n* gain, the wireless device **802***b* can perform one or more frequency, DC, and time estimation procedures.

In FIG. **8**, the ADC **810**, the RxFIR filter **830**, the detector **840**, the RSSI calculator **850**, and the AGC **860** are illustrated as being implemented in a DSP **820**. In some aspects, however, one or more of ADC **810**, the RxFIR filter **830**, the detector **840**, the RSSI calculator **850**, and the AGC **860** are implemented independently in the processor **204** (FIG. **2**) or in another element of the wireless device **202** (FIG. **2**).

As discussed above, the antenna switch **817** switches between the antennas **818***a*-**818***n* in the listening mode. However, if an antenna with poor reception is selected when a frame is transmitted to the wireless device **802***b*, the detector **840** may not detect the frame. Moreover, if transmission of the STF **704** (FIGS. **7** and **9**) ends before the RSSI calculator **850** has determined a receive power estimation for each antenna **818***a*-**818***n*, the processor **204** may not be able to choose the antenna **818***a*-**818***n* with the highest expected signal strength. In some embodiments, the preambles **702** and **902** (FIGS. **7** and **9**) can include a plurality of STFs **704**. In particular, the preambles **702** and **902** can include at least one STF **704** per receive antenna **818***a*-**818***n*. For example, the preambles **702** and **902** can include twice as many STFs **704** as receive antennas **818***a*-**818***n*, twice as many STFs **704** as receive antennas **818***a*-**818***n* minus one, or twice as many STFs **704** as receive antennas **818***a*-**818***n* plus one.

FIG. **9** is a block diagram showing another exemplary structure of a preamble **902** and payload **710** of a physical layer packet **900**. The illustrated embodiment corresponds to a wireless device **802***b* (FIG. **8**) having three antennas, referred to with respect to FIG. **9** as ANT0, ANT1, and ANT2. The preamble **902** includes seven STFs **704** (i.e., two times the number of receive antennas, plus one). The preamble **702** further includes the long training field (LTF) and the signal field (SIG) **708** as described above with respect to FIG. **7**.

In an exemplary sequence of events, a transmit channel may include noise **990** before the packet **900** is transmitted, for example, by the transmitter **210** (FIG. **2**). The antenna switch **817** (FIG. **8**) can select the antenna ANT0 for a first time period **991**, before the transmitter **210** transmits the first

STF **704**. Accordingly, the detector **840** (FIG. **8**) may not detect the packet **900**. The antenna switch **817** can select the antenna ANT1 for a second time period **992**. However, the antenna ANT1 may not be pointed towards the transmitter **210**, and therefore may not receive a strong enough signal for the detector **840** to detect the packet **900**. Similarly, the antenna switch **817** can select the antenna ANT2 for a third time period **993**. However, the antenna ANT2 may not be pointed towards the transmitter **210**, and therefore may not receive a strong enough signal for the detector **840** to detect the packet **900**.

The antenna switch **817** (FIG. **8**) can select the antenna ANT0 again for a fourth time period **994**. Because the preamble **902** includes at least one more STF **704** than the number of receive antennas, the antenna ANT0 may receive a strong enough signal for the detector **840** to detect the packet **900**. Accordingly, the RSSI calculator **850** (FIG. **8**) can estimate a receive power at the antenna ANT0, which can be stored in the memory **206** (FIG. **2**).

The antenna switch **817** (FIG. **8**) can select the antenna ANT1 again for a fifth time period **995**. Because the preamble **902** includes at least two more STFs **704** than the number of receive antennas, the RSSI calculator **850** (FIG. **8**) can estimate a receive power at the antenna ANT1, which can be stored in the memory **206** (FIG. **2**). Similarly, the antenna switch **817** (FIG. **8**) can select the antenna ANT2 again for a sixth time period **995**. Because the preamble **902** includes at least twice as many STFs **704** as the number of receive antennas, the RSSI calculator **850** (FIG. **8**) can estimate a receive power at the antenna ANT2, which can be stored in the memory **206** (FIG. **2**).

In an embodiment, the RSSI calculator **850** (FIG. **8**) may not estimate the receive power at the antenna ANT0 upon first detection of the packet **900**. In an embodiment, the antenna switch **817** (FIG. **8**) can select the antenna ANT0 again at a seventh time period **997**, and the RSSI calculator **850** can estimate a receive power at the antenna ANT0, which can be stored in the memory **206** (FIG. **2**). In various embodiments, additional STFs **704** can be included in the packet **900**, and the RSSI calculator **850** (FIG. **8**) can estimate a receive power at each antenna more than one time. In an embodiment, the time periods **991-997** can last for about the period T_stf.

In some embodiments, the detector **840** (FIG. **8**) may use more time to detect the frame than the RSSI calculator **850** (FIG. **8**) uses to estimate a receive power. Accordingly, in some embodiments, the STFs after detection can be shorter than the STFs before detection. Particularly, the preamble can include a detection STF (DSTF) having a first length T_stf1, and an estimation STF (ESTF) having a second length T_stf2. T_stf1 can be greater than T_stf2. In various embodiments, the DSTFs and ESTFs can include multiple repeated STF sequences or shorts. For example, T_stf1 can include between around 1-20 shorts, and more particularly around 10 shorts. T_stf2 can include between around 1-10 shorts, and more particularly around 5 shorts. Thus, in an embodiment, T_stf1 can be twice as long as T_stf2.

The preamble can include a number of DSTFs at least equal to the number of receiving antennas per receive front-end. In an embodiment, the preamble can include a number of DSTFs equal to the number of receiving antennas. In an embodiment, the preamble can include a number of DSTFs equal to the number of receiving antennas plus or minus one.

The preamble can include a number of ESTFs less than the number of receiving antennas per receive front-end. In an embodiment, the preamble can include a number of ESTFs equal to the number of receiving antennas. In an embodiment, the preamble can include a number of ESTFs equal to the number of receiving antennas plus or minus one.

FIG. **10** is a block diagram showing another exemplary structure of a preamble **1002** and payload **710** of a physical layer packet **1000**. The illustrated embodiment corresponds to a wireless device **802*b*** (FIG. **8**) having three antennas, referred to with respect to FIG. **9** as ANT0, ANT1, and ANT2. The preamble **1002** includes seven STFs **1004*d*** and **1004*e*** of various lengths (two times the number of receive antennas, plus one). Particularly, the preamble **1002** includes four DSTFs **1004*d*** (the number of receive antennas, plus one) and three ESTFs **1004*e*** (the number of receive antennas). The preamble **702** further includes the long training field (LTF) and the signal field (SIG) **708** as described above with respect to FIG. **7**.

In an exemplary sequence of events, the antenna switch **817** (FIG. **8**) can select the antenna ANT0 for a first time period **1091**, before the transmitter **210** transmits the first DSTF **1004*d***. Accordingly, the detector **840** (FIG. **8**) may not detect the packet **1000**. The antenna switch **817** can select the antenna ANT1 for a second time period **1092**. However, the antenna ANT1 may not be pointed towards the transmitter **210**, and therefore may not receive a strong enough signal for the detector **840** to detect the packet **1000**. Similarly, the antenna switch **817** can select the antenna ANT2 for a third time period **1093**. However, the antenna ANT2 may not be pointed towards the transmitter **210**, and therefore may not receive a strong enough signal for the detector **840** to detect the packet **1000**.

The antenna switch **817** (FIG. **8**) can select the antenna ANT0 again for a fourth time period **1094**. Because the preamble **1002** includes at least one more STF **704** than the number of receive antennas, the antenna ANT0 may receive a strong enough signal for the detector **840** to detect the packet **1000**. Accordingly, the RSSI calculator **850** (FIG. **8**) can estimate a receive power at the antenna ANT0, which can be stored in the memory **206** (FIG. **2**).

The antenna switch **817** (FIG. **8**) can select the antenna ANT1 again for a fifth time period **1095**. The RSSI calculator **850** (FIG. **8**) can estimate a receive power at the antenna ANT1, which can be stored in the memory **206** (FIG. **2**), based on the shorter ESTF **1004*e***. Similarly, the antenna switch **817** (FIG. **8**) can select the antenna ANT2 again for a sixth time period **1095**. The RSSI calculator **850** (FIG. **8**) can estimate a receive power at the antenna ANT2, which can be stored in the memory **206** (FIG. **2**), based on the shorter ESTF **1004*e***.

In an embodiment, the RSSI calculator **850** (FIG. **8**) may not estimate the receive power at the antenna ANT0 upon first detection of the packet **1000**. In an embodiment, the antenna switch **817** (FIG. **8**) can select the antenna ANT0 again at a seventh time period **1097**, and the RSSI calculator **850** can estimate a receive power at the antenna ANT0, which can be stored in the memory **206** (FIG. **2**). In various embodiments, additional ESTFs **1004*e*** can be included in the packet **1000**, and the RSSI calculator **850** (FIG. **8**) can estimate a receive power at each antenna more than one time. In various embodiments, the time periods **1091-1094** can last for about the period T_stf1, and the time periods **1095-1097** can last for about the period T_stf2.

In an embodiment, preambles including multiple STFs, DSTFs, and/or ESTFs can be referred to as training preambles, which can be included in training packets. Preambles with relatively fewer STFs, such as for example one STF, can be referred to as data preambles, which can be included in data packets. In various embodiments, the AP **104** (FIG. **1**) may use training preambles, such as the preambles **902** and/or

1002 described above with respect to FIGS. 9 and 10, while an STA 106a-106d is selecting one or a plurality of antennas. The AP 104 may use data preambles, such as the preamble 702 described above with respect to FIG. 7, after an STA 106a-106d has selected an antenna. In an embodiment, the STAs 106a-106d can be configured to request training preambles from the AP 104. In an embodiment, the STAs 106a-106d can be configured to request data preambles from the AP 104. In various embodiments, the AP 104 can default to either training preambles or data preambles and can transition to a different preamble type based on communication from an STA 106a-106d.

FIG. 11 is a flowchart 1100 of an exemplary method of selecting one of a plurality of antennas. Although the method of flowchart 1100 is described herein with reference to the wireless communication system 100 (FIG. 1), the wireless device 202 (FIG. 2), and the wireless device 802b (FIG. 8), a person having ordinary skill in the art will appreciate that the method of flowchart 1100 may be implemented by another device described herein, or any other suitable device. In an embodiment, the steps in flowchart 1100 may be performed by a processor or controller, e.g., the processor 204 (FIG. 2) or the DSP 220 (FIG. 2) in conjunction with the memory 206 (FIG. 2). Although the method of flowchart 1100 is described herein with reference to a particular order, in various embodiments, blocks herein may be performed in a different order, omitted, and/or additional blocks may be added.

First, at block 1110, the wireless device 802b receives, at a first antenna 818a, a first training field of a training frame. The first training field can be a short training field, such as DSTF 1004d, as discussed above with respect to FIG. 10. For example, the first training field can be the DSTF 1004d received in the time period 1094. The detector 840 can detect the frame 1000 based on the DSTF 1004d. In an embodiment, the RSSI calculator 850 can determine a received signal strength at the first antenna 818a, based on the first training field, which it can store in the memory 206.

Next, at block 1120, the wireless device 802b receives, at a second antenna 818b, a second training field of the training frame. The second training field can be a short training field, such as ESTF 1004e, as discussed above with respect to FIG. 10. For example, the second training field can be the ESTF 1004e received in the time period 1095. Accordingly, the second training field can be shorter than the first training field. The RSSI calculator 850 can determine a received signal strength at the second antenna 818b, based on the second training field, which it can store in the memory 206.

Then, at block 1130, the processor 204 selects one of the first and second antenna based on at least one training field (e.g., a short training field). For example, the processor 204 can cause the antenna switch 817 to select the antenna with the strongest signal strength. In an embodiment, the processor 204 can select one of the first and second antenna 818a-818b based on the received signal strengths associated with the first and second training fields (e.g., short training fields).

In an embodiment, the first antenna 818a can receive a third training field, which could be a short training field such as the ESTF 1004e received during the time period 1097. The RSSI calculator 850 can determine a received signal strength at the first antenna 818a, based on the third training field, which it can store in the memory 206. Accordingly, the processor 204 can select one of the first and second antenna 818a-818b based on the received signal strengths associated with the second and third training field (e.g., short training fields)s.

In various embodiments, the training frame can include a number of training fields (e.g., short training fields) equal to or greater than two times the number of antennas associated with the receiver front-end. Particularly, the training frame can include a number of training fields equal to two times the number of the plurality of antennas, plus one. The first and second training fields can each include a plurality of sequences of values (e.g., shorts). In an embodiment, the first training field can include more sequences of values (e.g., shorts) than the second training field.

In an embodiment, the transmitter 210 can transmit a communication indicating that subsequent frames will be data frames. For example, the wireless device 802b can send a message to the AP 104 informing the AP 104 that the wireless device 802b is no longer in an antenna selection mode. As another example, the wireless device 802b can send a request to the AP 104 that subsequent frames be data frames. As another example, the AP 104 can be configured to transmit a preset or dynamically determined number of training frames before automatically reverting to data frames. The AP 104 can transmit the data frame, such as the frame 700 (FIG. 7). The wireless device 802b can receive the data frame at the selected antenna. The data frame can include fewer training fields (e.g., short training fields) than the training frame.

FIG. 12 is a functional block diagram of an apparatus for wireless communication 1200 in accordance with an exemplary embodiment of the invention. The apparatus for wireless communication 1200 includes only those components useful for describing some prominent features of implementations within the scope of the claims. Those skilled in the art will appreciate that an apparatus for wireless communication may have more components than the simplified apparatus 1200. The apparatus for wireless communication 1200 includes first means 1210 for receiving a first training field (e.g., short training field) of a training frame, second means 1220 for receiving a second training field (e.g., short training field) of the training frame, and means 1230 for selecting one of the first and second means 1210 and 1220 for receiving based on at least one training field (e.g., short training field).

In an embodiment, the first means 1210 for receiving a first training field of a training frame can be configured to perform one or more of the functions described above with respect to block 1110 (FIG. 11). In various embodiments, the first means 1210 for receiving a first training field (e.g., short training field) of a training frame can be implemented by one or more of the receivers 212 (FIG. 2) and 620a-620n (FIG. 6) and the antennas 216 (FIG. 2), 518a-518n (FIG. 5), 618a-618n (FIG. 6), and 818a-818n (FIG. 8).

In an embodiment, the second means 1220 for receiving a second training field of the training frame can be configured to perform one or more of the functions described above with respect to block 1120 (FIG. 11). In various embodiments, the second means 1220 for receiving a second training field of the training frame can be implemented by one or more of the receivers 212 (FIG. 2) and 620a-620n (FIG. 6) and the antennas 216 (FIG. 2), 518a-518n (FIG. 5), 618a-618n (FIG. 6), and 818a-818n (FIG. 8).

In an embodiment, the means 1230 for selecting one of the first and second means 1210 and 1220 for receiving based on at least one training field (e.g., short training field) can be configured to perform one or more of the functions described above with respect to block 1130 (FIG. 11). In various embodiments, the first means 1230 for selecting one of the first and second means 1210 and 1220 for receiving based on at least one training field can be implemented by one or more of the processor 204 (FIG. 2), the memory 206 (FIG. 2), the DSP 220 (FIG. 2), and the antenna switch 817 (FIG. 8).

FIG. 13 is a flowchart 1300 of an exemplary method of wireless communication. Although the method of flowchart 1300 is described herein with reference to the wireless communication system **100** (FIG. **1**), the wireless device **202** (FIG. **2**), and the wireless device **802***b* (FIG. **8**), a person having ordinary skill in the art will appreciate that the method of flowchart **1300** may be implemented by another device described herein, or any other suitable device. In an embodiment, the steps in flowchart **1300** may be performed by a processor or controller, e.g., the processor **204** (FIG. **2**) or the DSP **220** (FIG. **2**) in conjunction with the memory **206** (FIG. **2**). Although the method of flowchart **1300** is described herein with reference to a particular order, in various embodiments, blocks herein may be performed in a different order, omitted, and/or additional blocks may be added.

First, at block **1310**, the AP **104** generates a training frame. The training frame includes a first and second training field (e.g., short training fields). For example, the processor **204** (FIG. **2**) can generate the training frame **1000** (FIG. **10**). The first training field can be a short training field, such as DSTF **1004***d* (FIG. **10**). The second training field can be an ESTF **1004***e* (FIG. **10**). The processor **204** can store the training frame, for example, in the memory **206**.

Next, at block **1320**, the AP **104** transmits the training frame to the wireless device **802***b*, which includes the plurality of antennas **818***a*-**818***b*. The AP **104** can transmit the training frame via, for example, the transmitter **210** and the antenna **216**. The training frame includes a number of training fields (e.g., short training fields) equal to or greater than two times the number of the plurality of antennas **818***a*-**818***n*. Particularly, the training frame can include a number of training fields equal to two times the number of the plurality of antennas, plus one. The first and second training fields can each include a plurality of sequences of values (e.g., shorts). In an embodiment, the first training field can include more sequences of values (e.g., shorts) than the second training field.

In an embodiment, the AP **104** can receive a communication indicating that subsequent frames will be data frames. For example, the AP **104** can receive a message from the wireless device **802***b* informing the AP **104** that the wireless device **802***b* is no longer in an antenna selection mode. As another example, the AP **104** can receive a request from the wireless device **802***b* that subsequent frames be data frames. As another example, the AP **104** can be configured to transmit a preset or dynamically determined number of training frames before automatically reverting to data frames. The AP **104** can transmit the data frame, such as the frame **700** (FIG. **7**). The wireless device **802***b* can receive the data frame at the selected antenna. The data frame can include fewer training fields than the training frame.

FIG. **14** is a functional block diagram of an apparatus for wireless communication **1400** in accordance with an exemplary embodiment of the invention. The apparatus for wireless communication **1400** includes only those components useful for describing some prominent features of implementations within the scope of the claims. Those skilled in the art will appreciate that an apparatus for wireless communication may have more components than the simplified apparatus **1400** shown in FIG. **14**. The apparatus for wireless communication **1400** includes means **1410** for generating a training frame including a first and second training field and means **1420** for transmitting the training frame to a wireless device including a plurality of antennas.

In an embodiment, the means **1410** for generating a training frame including a first and second training field (e.g., short training field) can be configured to perform one or more of the functions described above with respect to block **1310** (FIG. **13**). In various embodiments, the means **1410** for generating a training frame including a first and second training field can be implemented by one or more of the processor **204** (FIG. **2**), the memory **206** (FIG. **2**), and the DSP **220** (FIG. **2**).

In an embodiment, the means **1420** for transmitting the training frame to a wireless device including a plurality of antennas can be configured to perform one or more of the functions described above with respect to block **1320** (FIG. **13**). In various embodiments, the means **1420** for transmitting the training frame to a wireless device including a plurality of antennas can be implemented by one or more of the transmitters **210** (FIG. **2**), **514***a*-**514***n* (FIG. **5**), and **614***a*-**614***n* (FIG. **6**) and the antennas **216** (FIG. **2**), **516***a*-**516***b* (FIG. **5**), and **616***a*-**616***n* (FIG. **6**).

As used herein, the term "determining" encompasses a wide variety of actions. For example, "determining" may include calculating, computing, processing, deriving, investigating, looking up (e.g., in a table, a database, or another data structure), ascertaining and the like. "Determining" may also include receiving (e.g., information), accessing (e.g., data in a memory), and the like. "Determining" may also include resolving, selecting, choosing, establishing, and the like. Further, a "channel width" as used herein may encompass or may also be referred to as a bandwidth in certain aspects.

As used herein, a phrase referring to "at least one of" a list of items refers to any combination of those items, including single members. As an example, "at least one of: a, b, or c" is intended to cover: a, b, c, a-b, a-c, b-c, and a-b-c.

The various operations of methods described above may be performed by any suitable means capable of performing the operations, e.g., various hardware components, software components, circuits, and modules. Generally, any operations illustrated in the Figures may be performed by corresponding functional means capable of performing the operations.

The various illustrative logical blocks, modules, and circuits described in connection with the present disclosure may be implemented or performed with a general purpose processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array signal (FPGA) or other programmable logic device (PLD), discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A general purpose processor may be a microprocessor, but in the alternative, the processor may be any commercially available processor, controller, microcontroller, or state machine. A processor may also be implemented as a combination of computing devices, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration.

The methods disclosed herein include one or more steps or actions for achieving the described method. The method steps and/or actions may be interchanged with one another without departing from the scope of the claims. In other words, unless a specific order of steps or actions is specified, the order and/or use of specific steps and/or actions may be modified without departing from the scope of the claims.

The functions described may be implemented in hardware, software, firmware, or any combination thereof. If implemented in software, the functions may be stored as one or more instructions on a computer-readable medium. A storage media may be any available media that can be accessed by a computer. For example, such computer-readable media can include RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium that can be used to carry or store desired program code in the form of instructions or data structures and that can be accessed by a computer. Disk and disc, as used herein, include compact disc (CD), laser disc, optical disc, digital versatile disc (DVD), floppy disk, and Blu-ray® disc where disks usually reproduce data magnetically, while discs reproduce data optically with lasers.

Thus, certain aspects may include a computer program product for performing the operations presented herein. For example, such a computer program product may include a computer readable medium having instructions stored (and/or encoded) thereon, the instructions being executable by one or more processors to perform the operations described herein. For certain aspects, the computer program product may include packaging material.

Software or instructions may also be transmitted over a transmission medium. For example, if the software is transmitted from a website, server, or other remote source using a coaxial cable, fiber optic cable, twisted pair, digital subscriber line (DSL), or wireless technologies such as infrared, radio, and microwave, then the coaxial cable, fiber optic cable, twisted pair, DSL, or wireless technologies such as infrared, radio, and microwave are included in the definition of transmission medium.

Further, it should be appreciated that modules and/or other appropriate means for performing the methods and techniques described herein can be downloaded or otherwise obtained by a user terminal or base station as applicable. For example, such a device can be coupled to a server to facilitate the transfer of means for performing the methods described herein. Alternatively, various methods described herein can be provided via storage means (e.g., RAM, ROM, a physical storage medium such as a compact disc (CD) or floppy disk, etc.), such that a user terminal or base station can obtain the various methods upon coupling or providing the storage means to the device. Moreover, any other suitable technique for providing the methods and techniques described herein to a device can be utilized.

It is to be understood that the claims are not limited to the precise configuration and components illustrated above. Various modifications, changes and variations may be made in the arrangement, operation, and details of the methods and apparatus described above without departing from the scope of the claims.

While the foregoing is directed to aspects of the present disclosure, other and further aspects of the disclosure may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

What is claimed is:

1. A method of selecting one of a plurality of antennas, comprising:

receiving, at a first antenna, a first training field of a training frame;

detecting the training frame based on the first training field;

receiving, at a second antenna, a second training field of the training frame;

determining a received signal strength at the second antenna based on the second training field;

receiving at the first antenna a third training field of the training frame;

determining a received signal strength at the first antenna, based on the third training field; and

selecting one of the first and second antennas based on the determined received signal strengths.

2. The method of claim **1**, wherein the training frame comprises a number of training fields equal to or greater than two times the number of the plurality of antennas.

3. The method of claim **1**, wherein the training frame comprises a number of training fields equal to two times the number of the plurality of antennas, plus one.

4. The method of claim **1**, wherein the first and second training fields each comprise a plurality of sequences of values.

5. The method of claim **4**, wherein the first training field comprises more sequences of values than the second training field.

6. The method of claim **1**, further comprising:

transmitting a communication indicative that subsequent frames will be data frames; and

receiving, at the selected antenna, a data frame,

wherein the data frame comprises fewer training fields than the training frame.

7. The method of claim **1**, further comprising selectively connecting the first and second antennas to a receiver of a wireless device.

8. The method of claim **1**, further comprising using an antenna switch to selectively connect the first and second antennas to a receiver of a wireless device.

9. The method of claim **1**, further comprising:

amplifying an analog signal received from the first and second antennas;

converting the analog signal to a digital signal;

generating a receive power estimate for the selected antenna; and

selecting one of the first and second antennas based on the receive power estimate.

10. A method of wireless communication, comprising:

generating a training frame to be transmitted to a wireless device comprising a plurality of antennas, the training frame comprising at least a first, second, and third training field; and

transmitting the training frame to the wireless device, such that the training frame is detectable by the wireless device based on the first training field, and such that a received signal strength at a first antenna of the wireless device is determinable based on the third training field, and such that a received signal strength at a second antenna of the wireless device is determinable based on the second training field, and such that one of the first and second antennas of the wireless device are selectable based on the determined received signal strengths, wherein the training frame comprises a number of training fields equal to or greater than two times the number of the plurality of antennas.

11. The method of claim **10**, wherein the number of training fields is equal to two times the number of the plurality of antennas, plus one.

12. The method of claim **10**, wherein the first and second training fields each comprise a plurality of sequences of values.

13. The method of claim **12**, wherein the first training field comprises more sequences of values than the second training field.

14. The method of claim **10**, further comprising:

receiving a communication indicative that subsequent frames will be data frames; and

transmitting a data frame,

wherein the data frame comprises fewer training fields than the training frame.

15. A wireless device configured to select one of a plurality of antennas, comprising:

a first antenna configured to receive a first and third training field of a training frame;

a processor configured to detect the training frame based on the first training field;

a second antenna configured to receive a second training field of the training frame, wherein the processor is further configured to:

determine a received signal strength at the second antenna based on the second training field;

determine a received signal strength at the first antenna based on the third training field; and

select one of the first and second antennas based on the determined received signal strengths.

16. The device of claim **15**, wherein the training frame comprises a number of training fields equal to or greater than two times the number of the plurality of antennas.

17. The device of claim **15**, wherein the training frame comprises a number of training fields equal to two times the number of the plurality of antennas, plus one.

18. The device of claim **15**, wherein the first and second training fields each comprise a plurality of sequences of values.

19. The device of claim **18**, wherein the first training field comprises more sequences of values than the second training field.

20. The device of claim **15**, further comprising:

a transmitter configured to transmit a communication indicative that subsequent frames will be data frames,

wherein the selected antenna is configured to receive a data frame, and

the data frame comprises fewer training fields than the training frame.

21. The device of claim **15**, further comprising an antenna switch to selectively connect the first and second antennas to a receiver of the wireless device.

22. The device of claim **15**, further comprising:

an amplifier to amplify an analog signal received from the first and second antennas;

an analog to digital converter to convert the analog signal to a digital signal; and

a calculator to generate a receive power estimate for the selected antenna, wherein an antenna switch is configured to select one of the first and second antennas based on the receive power estimate.

23. A device configured to communicate wirelessly, comprising:

a processor configured to generate a training frame to be transmitted to a wireless device comprising a plurality of antennas, the training frame comprising at least a first, second, and third training field; and

a transmitter configured to transmit the training frame to the wireless device such that the training frame is detectable by the wireless device based on the first training field, and such that a received signal strength at a first antenna of the wireless device is determinable based on the third training field, and such that a received signal strength at a second antenna of the wireless device is determinable based on the second training field, and such that one of the first and second antennas of the wireless device are selectable based on the determined received signal strengths, wherein the training frame comprises a number of training fields equal to or greater than two times the number of the plurality of antennas.

24. The device of claim **23**, wherein the number of training fields is equal to two times the number of the plurality of antennas, plus one.

25. The device of claim **23**, wherein the first and second training fields each comprise a plurality of sequences of values.

26. The device of claim **25**, wherein the first training field comprises more sequences of values than the second training field.

27. The device of claim **23**, further comprising:

a receiver configured to receive a communication indicative that subsequent frames will be data frames,

wherein the transmitter is further configured to transmit a data frame, and

the data frame comprises fewer training fields than the training frame.

28. A non-transitory computer-readable medium comprising code that, when executed, causes an apparatus to:

receive, at a first antenna, a first training field of a training frame;

detect the training frame based on the first training field;

receive, at a second antenna, a second training field of the training frame;

determine a received signal strength at the second antenna based on the second training field;

receive, at the first antenna, a third training field of the training frame;

determine a received signal strength at the first antenna, based on the third training field; and

select one of the first and second antenna based on the determined received signal strengths.

29. The medium of claim **28**, wherein the training frame comprises a number of training fields equal to two times the number of the plurality of antennas, plus one.

30. The medium of claim **28**, further comprising code that, when executed, causes the apparatus to:

transmit a communication indicative that subsequent frames will be data frames; and

receive, at the selected antenna, a data frame,

wherein the data frame comprises fewer training fields than the training frame.

31. A non-transitory computer-readable medium comprising code that, when executed, causes an apparatus to:

generate a training frame to be transmitted to a wireless device comprising a plurality of antennas, the training frame comprising at least a first, second, and third training field; and

transmit the training frame to the wireless device, such that the training frame is detectable by the wireless device based on the first training field, and such that a received signal strength at a first antenna of the wireless device is determinable based on the third training field, and such that a received signal strength at a second antenna of the wireless device is determinable based on the second training field, and such that one of the first and second antennas of the wireless device are selectable based on the determined received signal strengths, wherein the training frame comprises a number of training fields equal to or greater than two times the number of the plurality of antennas.

32. The medium of claim **31**, wherein the number of training fields is equal to two times the number of the plurality of antennas, plus one.

33. The medium of claim **31**, further comprising code that, when executed, causes the apparatus to:

receive a communication indicative that subsequent frames will be data frames; and

transmit a data frame,

wherein the data frame comprises fewer training fields than the training frame.

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